

20030228006



**PROGRAM MANAGER
RMA CONTAMINATION CLEANUP**

U.S. ARMY
MATERIEL COMMAND

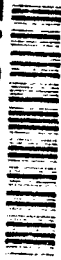
— COMMITTED TO PROTECTION OF THE ENVIRONMENT —

TECHNICAL SUPPORT FOR
ROCKY MOUNTAIN ARSENAL

FINAL
WATER REMEDIAL INVESTIGATION REPORT

(Version 3.3)
Volume III

AD-A277 542



94-09271



DTIC
ELECTE
MAR 25 1994
S F D

EBASCO SERVICES INCORPORATED
Applied Environmental, Inc.
CH2M HILL DataChem, Inc.
R.L. Stollar & Associates, Inc.

This document has been approved
for public release and sale; its
distribution is unlimited.

REQUESTS FOR COPIES OF THIS DOCUMENT
SHOULD BE REFERRED TO THE PROGRAM MANAGER
FOR THE ROCKY MOUNTAIN ARSENAL CONTAMINATION CLEANUP,
AMXRM ABERDEEN PROVING GROUND, MARYLAND

9 4 3 24 069

**TECHNICAL SUPPORT FOR
ROCKY MOUNTAIN ARSENAL**

**FINAL
WATER REMEDIAL INVESTIGATION REPORT**

**(Version 3.3)
Volume III**

July 1989

**Contract Number DAAK11-84-D-0016
and DAAA-15-88-D-0024**

Prepared By

**EBASCO SERVICES INCORPORATED
R. L. Stollar & Associates, Inc.
Hunter/ESE, Inc.
Harding Lawson Associates**

Prepared For

**U.S. Army Program Manager's Office for
Rocky Mountain Arsenal Contamination Cleanup**

Accession For	
NTIS CRA21	✓
DTIC TAB	
Unannounced	
Justification	
By	
Distribution	
Availability Codes	
Dist	Avail and/or Supplier
A-1	

THE INFORMATION AND CONCLUSIONS PRESENTED IN THIS REPORT REPRESENT THE OFFICIAL POSITION OF THE DEPARTMENT OF THE ARMY UNLESS EXPRESSLY MODIFIED BY A SUBSEQUENT DOCUMENT. THIS REPORT CONSTITUTES THE RELEVANT PORTION OF THE ADMINISTRATIVE RECORD FOR THIS CERCLA OPERABLE UNIT.

THE USE OF TRADE NAMES IN THIS REPORT DOES NOT CONSTITUTE AN OFFICIAL ENDORSEMENT OR APPROVAL OF THE USE OF SUCH COMMERCIAL PRODUCTS. THIS REPORT MAY NOT BE CITED FOR PURPOSES OF ADVERTISEMENT.

VOLUME I

TABLE OF CONTENTS

	PAGE
EXECUTIVE SUMMARY	
1.0 INTRODUCTION	1-1
1.1 Purpose	1-1
1.2 Scope of Work	1-1
1.3 Methodology	1-2
1.4 Overview	1-3
1.5 Problem Definition	1-5
1.6 Previous Investigations	1-5
2.0 ENVIRONMENTAL SETTING	2-1
2.1 Physiography	2-1
2.2 Surface Water Hydrology	2-1
2.3 Geology	2-5
2.4 Unconfined Flow System	2-6
2.4.1 Hydraulic Properties	2-7
2.4.2 Potentiometric Surface	2-9
2.4.3 Water Level Fluctuations	2-11
2.4.4 Recharge and Discharge	2-11
2.5 Denver Aquifer	2-14
2.5.1 Hydraulic Properties	2-14
2.5.2 Distribution of Hydraulic Head	2-15
2.5.3 Recharge and Discharge	2-15
2.6 Surface Water - Groundwater Interaction	2-16
3.0 NATURE AND EXTENT OF CONTAMINATION	3-1
3.1 Surface Water Quality	3-3
3.2 Groundwater Quality	3-3
3.2.1 Volatile Halogenated Organics	3-4
3.2.2 Dicyclopentadiene	3-5
3.2.3 Volatile Aromatics	3-6
3.2.4 Organosulfur Compounds	3-7
3.2.5 Diisopropylmethyl Phosphonate	3-10

TABLE OF CONTENTS (Continued)

	PAGE
3.2.6 DBCP	3-11
3.2.7 Organochlorine Pesticides	3-12
3.2.8 Arsenic	3-13
3.2.9 Fluoride	3-14
3.2.10 Chloride	3-16
3.2.11 GC/MS Analysis	3-18
3.2.12 Vertical Extent of Contamination	3-18
4.0 CONTAMINATION ASSESSMENT	4-1
4.1 Hydrologic Mechanisms for Contamination of Surface Water	4-1
4.2 Hydrologic Mechanisms for the Introduction of Contaminants to Groundwater	4-2
4.3 Hydrologic Model of Groundwater Flow and Contaminant Migration	4-6
4.3.1 Conceptual Model of Groundwater Flow	4-7
4.3.2 Numerical Models of Groundwater Flow	4-10
4.3.3 Conceptual Model of Contaminant Migration	4-14
4.4 Chemical Properties and Hydrochemical Processes Affecting Contaminant Migration	4-17
4.4.1 Physical and Chemical Properties	4-18
4.4.2 Attenuation of Target Analytes	4-30
4.5 Contaminant Source Areas and Pathways	4-37
4.5.1 South Plants Source Area and Pathways	4-37
4.5.2 Basin A Source Area and Pathways	4-39
4.5.3 Basin F Source Area and Pathways	4-42
4.5.4 North Plants Source Area and Pathway	4-43
4.5.5 Western Tier Source Areas and Pathways	4-44
4.5.6 Chemical Sewer	4-46
4.5.7 Other Source Areas and Pathways	4-47
4.6 Contaminant Migration and Alteration Along Major Groundwater Pathways	4-48
4.6.1 South Plants Pathways	4-49
4.6.2 Basin A-Basin A Neck Pathways	4-50
4.6.3 Central Pathways	4-52
4.6.4 Basin F Pathway	4-53
4.6.5 Western Tier Pathways	4-56
4.7 Vertical Contaminant Migration	4-57
4.7.1 South Plants	4-58
4.7.2 Basins C and F	4-59
4.7.3 North Boundary Containment System	4-60

TABLE OF CONTENTS (Continued)

	PAGE
5.0 SUMMARY AND CONCLUSIONS	5-1
6.0 REFERENCES	6-1

VOLUME I LIST OF TABLES

	PAGE
Table 2.1 Streamflow Statistics for Gaging Stations at RMA During Water Years 1986 and 1987.	2-3
Table 2.2 Hydraulic Conductivity Estimates for Hydrogeologic Units of the Unconfined Flow System	2-8
Table 2.3 Estimated Recharge to the Unconfined Flow System	2-13
Table 3.1 Representative Concentrations for Naturally Occurring Constituents in RMA Upgradient Unconfined Wells	3-15
Table 4.1 Model Estimated Recharge and Discharge for the Unconfined Flow System.	4-9
Table 4.2 Physiochemical Properties of Select RMA Contaminants	4-20
Table 4.3 First Order Biodegradation Constants and Half Lives for Environmental Processes Controlling Solvent Transformations ^a . . .	4-34
Table 4.4 Mechanisms for the Introduction of Contaminants to Groundwater .	4-40

VOLUME I LIST OF FIGURES

FIGURE	PAGE
1.1 Location Map of Rocky Mountain Arsenal	1-9
1.2 Significant Features at Rocky Mountain Arsenal	1-10
2.1 RMA Stratigraphic Column	2-19
2.2 Saturated Thickness Map for Unconfined Flow System	2-20
2.3 Hydrogeologic Unit Map for Unconfined Flow System	2-21
2.4 Potentiometric Surface of the Unconfined Flow System, Third Quarter, FY1987.	2-22
2.5 Potentiometric Surface of Denver Zone 4, Third Quarter, FY1987.	2-23
2.6 Potentiometric Surface of Denver Zone 3, Third Quarter, FY1987.	2-24
2.7 Potentiometric Surface of Denver Zone 2, Third Quarter, FY1987.	2-25
2.8 Potentiometric Surface of Denver Zone 1, Third Quarter, FY1987.	2-26
2.9 Potentiometric Surface of Denver Zone 1U, Third Quarter, FY1987.	2-27
2.10 Potentiometric Surface of Denver Zone A, Third Quarter, FY1987	2-28
3.1 RMA Contaminant Migration Pathways	3-21
3.2 Surface Water Quality Fall 85 - Fall 87; Multiple Detected Compounds.	3-22
3.3 Summed Volatile Halogenated Organics Plumes Unconfined Groundwater Flow System, 3rd Quarter FY1987	3-23
3.4 Dicyclopentadiene Plumes Unconfined Groundwater Flow System, 3rd Quarter FY1987	3-24
3.5 Summed Volatile Aromatics Plumes Unconfined Groundwater Flow System, 3rd Quarter FY1987.	3-25
3.6 Organosulfur Compounds (CPMS, CPMSO, CPMSO ₂) Plumes Unconfined Groundwater Flow System, 3rd Quarter FY1987	3-26
3.7 Diisopropylmethyl Phosphonate Plumes Unconfined Groundwater Flow System, 3rd Quarter FY 1987	3-27

VOLUME I LIST OF FIGURES (Continued)

	PAGE
3.8 Dibromochloropropane Plumes Unconfined Groundwater Flow System, 3rd Quarter FY1987	3-28
3.9 Dieldrin Plumes Unconfined Groundwater Flow System, 3rd Quarter FY1987	3-29
3.10 Areal Extent of Inorganic Analytes in the Unconfined Flow System.	3-30
3.11 Areal Extent of Inorganic Analytes Denver Formation Zone B	3-31
3.12 Areal Extent of Inorganic Analytes Denver Formation Zone A	3-32
3.13 Areal Extent of Inorganic Analytes Denver Formation Zone 1U.	3-33
3.14 Areal Extent of Inorganic Analytes Denver Formation Zone 1	3-34
3.15 Areal Extent of Inorganic Analytes Denver Formation Zone 2	3-35
3.16 Areal Extent of Inorganic Analytes Denver Formation Zone 3	3-36
3.17 Areal Extent of Inorganic Analytes Denver Formation Zone 4	3-37
3.18 Areal Extent of Inorganic Analytes Denver Formation Zone 5	3-38
3.19 Areal Extent of Inorganic Analytes Denver Formation Zones 6 and 7	3-39
3.20 Areal Extent of Organic Analytes in the Unconfined Flow System	3-40
3.21 Areal Extent of Organic Analytes Denver Formation Zone A.	3-41
3.22 Areal Extent of Organic Analytes Denver Formation Zone 1U	3-42
3.23 Areal Extent of Organic Analytes Denver Formation Zone 1	3-43
3.24 Areal Extent of Organic Analytes Denver Formation Zone 2	3-44
3.25 Areal Extent of Organic Analytes Denver Formation Zone 3	3-45
3.26 Areal Extent of Organic Analytes Denver Formation Zone 4	3-46
3.27 Areal Extent of Organic Analytes Denver Formation Zones 5 and 6.	3-47
4.1 Potentiometric Surface and Groundwater Flow Directions of the Unconfined Flow System.	4-61
4.2 Transformations of Chlorinated Aliphatic Hydrocarbons	4-62
4.3 Location of Confirmed and Suspected Contamination Source Areas	4-63

VOLUME II

APPENDIX A

DENVER FM GEOLOGIC DATA

- A.1 DENVER ZONE SANDSTONE TOP AND BASE ELEVATIONS, AND THICKNESS**
- A.2 BEDROCK ELEVATIONS AND SCREENED DENVER FM ZONES OR UNITS**

APPENDIX B

HYDROLOGIC DATA

- B.1 SURFACE WATER DATA**
- B.2 ALLUVIAL WATER LEVEL DATA**
- B.3 DENVER FM WATER LEVEL DATA**
- B.4 ALLUVIAL AND DENVER FM AQUIFER TEST DATA**

APPENDIX C

TASK 44

- C.1 SUMMARY OF TASK 44 ACTIVITIES**
- C.2 WELL CONSTRUCTION DATA**
- C.3 WATER CHEMISTRY DATA FOR 1ST, 2ND AND 4TH QUARTER, FY87**

APPENDIX D

CHEMISTRY DATA

- D.1 3RD QUARTER FY87 CHEMISTRY DATA**
- D.2 EPA CHEMISTRY DATA**
- D.3 ALLUVIAL/UNCONFINED PLUME MAPS (D-1 TO D-9)**
- D.4 ALLUVIAL/UNCONFINED POINT PLOTS (D-10 TO D-26)**
- D.5 DENVER FM POINT PLOTS (D-27 TO D-168)**
- D.6 TASK 4/44 GC/MS ANALYSIS NETWORK DETECTION (D-168 TO D-188)**
- D.7 GC/MS DATA**

APPENDIX E

HYDROCHEMICAL PROPERTIES AND HYDROLOGIC CALCULATIONS

VOLUME II LIST OF FIGURES

- C-1 Generalized Bedrock Aquifer Monitor Well Construction (Denver Fm Well Completed in First Sandstone, Alluvium Unsaturated, Sandstone at the Alluvial-Bedrock Contact, Sandstone Partially Saturated)
- C-2 Generalized Bedrock Aquifer Monitor Well Construction (Denver Fm Well Completed in First Sandstone, Alluvium Unsaturated, Shale at the Alluvial-Bedrock Contact)
- C-3 Generalized Bedrock Aquifer Monitor Well Construction (Denver Fm Well Completed in First Sandstone, Alluvium Saturated, Sandstone at the Alluvial-Bedrock Contact)
- C-4 Generalized Bedrock Aquifer Monitor Well Construction (Denver Fm Well Completed in First Sandstone, Alluvium Saturated, Shale at the Alluvial-Bedrock Contact)
- C-5 Generalized Bedrock Aquifer Monitor Well Construction (Denver Fm Well Completed in Second Sandstone, Alluvium Saturated, Shale at the Alluvial-Bedrock Contact)
- C-6 Generalized Bedrock Aquifer Monitor Well Construction (Denver Fm Well Completed in Second Sandstone, Alluvium Unsaturated, Shale at the Alluvial-Bedrock Contact, First and Second Sandstone Saturated)
- C-7 Generalized Bedrock Aquifer Monitor Well Construction (Denver Fm Well Completed in Second Sandstone, Alluvium Unsaturated, Saturated Sandstone at the Alluvial-Bedrock Contact)
- C-8 Generalized Aquifer Monitor Well Construction
- C-9 Schematic Drawing of a Typical Cluster Well Installation
- C-10 Well Development Data Form
- D-1 Oxathiane Plumes Unconfined Groundwater Flow System, 3rd Quarter FY87
- D-2 Dithiane Plumes Unconfined Groundwater Flow System, 3rd Quarter FY87
- D-3 CPMS Plumes Unconfined Groundwater Flow System, 3rd Quarter FY87
- D-4 CPMSO Plumes Unconfined Groundwater Flow System, 3rd Quarter FY87
- D-5 CPMSO₂ Plumes Unconfined Groundwater Flow System, 3rd Quarter FY87
- D-6 1,1-Dichloroethylene Plumes Unconfined Groundwater Flow System, 3rd Quarter FY87

VOLUME II LIST OF FIGURES (Continued)

- D-7 T-1,2-Dichloroethylene Plumes Unconfined Groundwater Flow System, 3rd Quarter FY87
- D-8 1,2-Dichloroethane Plumes Unconfined Groundwater Flow System, 3rd Quarter FY87
- D-9 1,1,1-Trichloroethane Plumes Unconfined Groundwater Flow System, 3rd Quarter FY87
- D-10 Aldrin Detections Unconfined Groundwater Flow System, 3rd Quarter FY87
- D-11 Isodrin Detections Unconfined Groundwater Flow System, 3rd Quarter FY87
- D-12 pp-DDT Detections Unconfined Groundwater Flow System, 3rd Quarter FY87
- D-13 pp-DDE Detections Unconfined Groundwater Flow System, 3rd Quarter FY87
- D-14 Hexachlorocyclopentadiene Detections Unconfined Groundwater Flow System, 3rd Quarter FY87
- D-15 Chlordane Detections Unconfined Groundwater Flow System, 3rd Quarter FY87
- D-16 DMDS Detections Unconfined Groundwater Flow System, 3rd Quarter FY87
- D-17 Ethylbenzene Detections Unconfined Groundwater Flow System, 3rd Quarter FY87
- D-18 Toluene Detections Unconfined Groundwater Flow System, 3rd Quarter FY87
- D-19 m-Xylene Detections Unconfined Groundwater Flow System, 3rd Quarter FY87
- D-20 o,p-Xylene Detections Unconfined Groundwater Flow System, 3rd Quarter FY87
- D-21 Methylene Chloride Detections Unconfined Groundwater Flow System, 3rd Quarter FY87
- D-22 1,1-Dichloroethane Detections Unconfined Groundwater Flow System, 3rd Quarter FY87
- D-23 Carbon Tetrachloride Detections Unconfined Groundwater Flow System, 3rd Quarter FY87
- D-24 1,1,2-Trichloroethane Detections Unconfined Groundwater Flow System, 3rd Quarter FY87
- D-25 DMMP Detections Unconfined Groundwater Flow System, 3rd Quarter FY87
- D-26 MIBK Detections Unconfined Groundwater Flow System, 3rd Quarter FY87
- D-27 Aldrin Detections Denver Zone I, 3rd Quarter FY87

VOLUME II LIST OF FIGURES (Continued)

D-28	Dieldrin Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-29	Dieldrin Detections Denver Zone A, 3rd Quarter FY87
D-30	Dieldrin Detections Denver Zone 2, 3rd Quarter FY87
D-31	Dieldrin Detections Denver Zone 3, 3rd Quarter FY87
D-32	Endrin Detections Denver Zone 1, 3rd Quarter FY87
D-33	Endrin Detections Denver Zone 2, 3rd Quarter FY87
D-34	Endrin Detections Denver Zone 3, 3rd Quarter FY87
D-35	Isodrin Detections Denver Zone 2, 3rd Quarter FY87
D-36	pp-DDT Detections Denver Zone 2, 3rd Quarter FY87
D-37	DMDS Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-38	DMDS Detections Denver Zone 1, 3rd Quarter FY87
D-39	DMDS Detections Denver Zone 2, 3rd Quarter FY87
D-40	Oxathiane Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-41	Oxathiane Detections Denver Zone A, 3rd Quarter FY87
D-42	Oxathiane Detections Denver Zone 1u, 3rd Quarter FY87
D-43	Oxathiane Detections Denver Zone 1, 3rd Quarter FY87
D-44	Oxathiane Detections Denver Zone 2, 3rd Quarter FY87
D-45	Dithiane Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-46	Dithiane Detections Denver Zone A, 3rd Quarter FY87
D-47	Dithiane Detections Denver Zone 1u, 3rd Quarter FY87
D-48	Dithiane Detections Denver Zone 1, 3rd Quarter FY87
D-49	Dithiane Detections Denver Zone 2, 3rd Quarter FY87
D-50	Dithiane Detections Denver Zone 4, 3rd Quarter FY87
D-51	Oxathiane/Dithiane Detections Denver Zone VC/VCE 3rd Quarter FY87
D-52	Oxathiane/Dithiane Detections Denver Zone A 3rd Quarter FY87

VOLUME II LIST OF FIGURES (Continued)

D-53	Oxathiane/Dithiane Detections Denver Zone 1u 3rd Quarter FY87
D-54	Oxathiane/Dithiane Detections Denver Zone 2 3rd Quarter FY87
D-55	Oxathiane/Dithiane Detections Denver Zone 4 3rd Quarter FY87
D-56	Benzothiazole Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-57	Benzothiazole Detections Denver Zone A, 3rd Quarter FY87
D-58	Benzothiazole Detections Denver Zone 1u, 3rd Quarter FY87
D-59	Benzothiazole Detections Denver Zone 1, 3rd Quarter FY87
D-60	Benzothiazole Detections Denver Zone 2, 3rd Quarter FY87
D-61	Benzothiazole Detections Denver Zone 4, 3rd Quarter FY87
D-62	Benzothiazole Detections Zone 5, 3rd Quarter FY87
D-63	CPMS Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-64	CPMS Detections Denver Zone A, 3rd Quarter FY87
D-65	CPMS Detections Denver Zone 1u, 3rd Quarter FY87
D-66	CPMS Detections Denver Zone 1, 3rd Quarter FY87
D-67	CPMS Detections Denver Zone 2, 3rd Quarter FY87
D-68	CPMSO Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-69	CPMSO Detections Denver Zone 2, 3rd Quarter FY87
D-70	CPMSO ₂ Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-71	CPMSO ₂ Detections Denver Zone A, 3rd Quarter FY87
D-72	CPMSO ₂ Detections Denver Zone 1u, 3rd Quarter FY87
D-73	CPMSO ₂ Detections Denver Zone 1, 3rd Quarter FY87
D-74	CPMSO ₂ Detections Denver Zone 2, 3rd Quarter FY87
D-75	Benzene Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-76	Benzene Detections Denver Zone A, 3rd Quarter FY87
D-77	Benzene Detections Denver Zone 1u, 3rd Quarter FY87

VOLUME II LIST OF FIGURES (Continued)

D-78	Benzene Detections Denver Zone 1, 3rd Quarter FY87
D-79	Chlorobenzene Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-80	Chlorobenzene Detections Denver Zone A, 3rd Quarter FY87
D-81	Chlorobenzene Detections Denver Zone 1u, 3rd Quarter FY87
D-82	Chlorobenzene Detections Denver Zone 1, 3rd Quarter FY87
D-83	Chlorobenzene Detections Denver Zone 4, 3rd Quarter FY87
D-84	Chlorobenzene Detections Denver Zone 5, 3rd Quarter FY87
D-85	Ethylbenzene Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-86	Ethylbenzene Detections Denver Zone 2, 3rd Quarter FY87
D-87	Ethylbenzene Detections Denver Zone 5, 3rd Quarter FY87
D-88	Toluene Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-89	Toluene Detections Denver Zone 1, 3rd Quarter FY87
D-90	Toluene Detections Denver Zone 2, 3rd Quarter FY87
D-91	Toluene Detections Denver Zone 4, 3rd Quarter FY87
D-92	Toluene Detections Denver Zone 5, 3rd Quarter FY87
D-93	m-Xylene Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-94	m-Xylene Detections Denver Zone 2, 3rd Quarter FY87
D-95	m-Xylene Detections Denver Zone 5, 3rd Quarter FY87
D-96	o,p-Xylene Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-97	o,p-Xylene Detections Denver Zone 2, 3rd Quarter FY87
D-98	o,p-Xylene Detections Denver Zone 5, 3rd Quarter FY87
D-99	Chloroform Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-100	Chloroform Detections Denver Zone A, 3rd Quarter FY87
D-101	Chloroform Detections Denver Zone 1u, 3rd Quarter FY87
D-102	Chloroform Detections Denver Zone 1, 3rd Quarter FY87

VOLUME II LIST OF FIGURES (Continued)

D-103	Chloroform Detections Denver Zone 2, 3rd Quarter FY87
D-104	Chloroform Detections Denver Zone 5, 3rd Quarter FY87
D-105	Chloroform Detections Denver Zone 6, 3rd Quarter FY87
D-106	Trichloroethylene Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-107	Trichloroethylene Detections Denver Zone A, 3rd Quarter FY87
D-108	Trichloroethylene Detections Denver Zone 1u, 3rd Quarter FY87
D-109	Trichloroethylene Detections Denver Zone 1, 3rd Quarter FY87
D-110	Trichloroethylene Detections Denver Zone 2, 3rd Quarter FY87
D-111	Trichloroethylene Detections Denver Zone 3, 3rd Quarter FY87
D-112	Trichloroethylene Detections Denver Zone 4, 3rd Quarter FY87
D-113	Tetrachloroethylene Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-114	Tetrachloroethylene Detections Denver Zone A, 3rd Quarter FY87
D-115	Tetrachloroethylene Detections Denver Zone 1, 3rd Quarter FY87
D-116	Tetrachloroethylene Detections Denver Zone 2, 3rd Quarter FY87
D-117	Methylene Chloride Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-118	Methylene Chloride Detections Denver Zone 2, 3rd Quarter FY87
D-119	Methylene Chloride Detections Denver Zone 6, 3rd Quarter FY87
D-120	1,1-Dichloroethylene Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-121	1,1-Dichloroethylene Detections Denver Zone A, 3rd Quarter FY87
D-122	1,1-Dichloroethane Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-123	1,1-Dichloroethane Detections Denver Zone A, 3rd Quarter FY87
D-124	1,1-Dichloroethane Detections Denver Zone 2, 3rd Quarter FY87
D-125	T-1,2-Dichloroethylene Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-126	T-1,2-Dichloroethylene Detections Denver Zone A 3rd Quarter FY87
D-127	1,2-Dichloroethane Detections Denver Zone VC/VCE, 3rd Quarter FY87

VOLUME II LIST OF FIGURES (Continued)

D-128	1,2-Dichloroethane Detections Denver Zone A, 3rd Quarter FY87
D-129	1,2-Dichloroethane Detections Denver Zone 1, 3rd Quarter FY87
D-130	1,2-Dichloroethane Detections Denver Zone 2, 3rd Quarter FY87
D-131	1,2-Dichloroethane Detections Denver Zone 4, 3rd Quarter FY87
D-132	Carbon Tetrachloride Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-133	Carbon Tetrachloride Detections Denver Zone A, 3rd Quarter FY87
D-134	1,1,2-Trichloroethane Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-135	DBCP Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-136	DBCP Detections Denver Zone A, 3rd Quarter FY87
D-137	DBCP Detections Denver Zone 1, 3rd Quarter FY87
D-138	DBCP Detections Denver Zone 2, 3rd Quarter FY87
D-139	DBCP Detections Denver Zone 4, 3rd Quarter FY87
D-140	DCPD Detections Denver Zone 1, 3rd Quarter FY87
D-141	DCPD Detections Denver Zone 2, 3rd Quarter FY87
D-142	Diisopropylmethyl Phosphonate Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-143	Diisopropylmethyl Phosphonate Detections Denver Zone A, 3rd Quarter FY87
D-144	Diisopropylmethyl Phosphonate Detections Denver Zone 1u, 3rd Quarter FY87
D-145	Diisopropylmethyl Phosphonate Detections Denver Zone 1, 3rd Quarter FY87
D-146	Diisopropylmethyl Phosphonate Detections Denver Zone 2, 3rd Quarter FY87
D-147	Diisopropylmethyl Phosphonate Detections Denver Zone 3, 3rd Quarter FY87
D-148	Diisopropylmethyl Phosphonate Detections Denver Zone 5, 3rd Quarter FY87
D-149	DMMP Detections Denver Zone 1, 3rd Quarter FY87
D-150	DMMP Detections Denver Zone 2, 3rd Quarter FY87
D-151	Chloride Detections Denver Zone B, 3rd Quarter FY87

VOLUME II LIST OF FIGURES (Continued)

D-152	Chloride Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-153	Chloride Detections Denver Zone 1u, 3rd Quarter FY87
D-154	Chloride Detections Denver Zone 5, 3rd Quarter FY87
D-155	Chloride Detections Denver Zone 6, 3rd Quarter FY87
D-156	Chloride Detections Denver Zone 7, 3rd Quarter FY87
D-157	Fluoride Detections Denver Zone B, 3rd Quarter FY87
D-158	Fluoride Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-159	Fluoride Detections Denver Zone 3, 3rd Quarter FY87
D-160	Fluoride Detections Denver Zone 6, 3rd Quarter FY87
D-161	Fluoride Detections Denver Zone 7, 3rd Quarter FY87
D-162	Arsenic Detections Denver Zone VC/VCE, 3rd Quarter FY87
D-163	Arsenic Detections Denver Zone A, 3rd Quarter FY87
D-164	Arsenic Detections Denver Zone 1u, 3rd Quarter FY87
D-165	Arsenic Detections Denver Zone 1, 3rd Quarter FY87
D-166	Arsenic Detections Denver Zone 2, 3rd Quarter FY87
D-167	Arsenic Detections Denver Zone 4, 3rd Quarter FY87
D-168	Arsenic Detections Denver Zone 5, 3rd Quarter FY87
D-169	Task 4/44 GC/MS Analysis Network 1,1,2,2-Tetrachloroethane Detections
D-170	Task 4/44 GC/MS Analysis Network 1,1,2-Trichloroethane Detections
D-171	Task 4/44 GC/MS Analysis Network 2,6,10,14-Tetramethylhexadecane Detections
D-172	Task 4/44 GC/MS Analysis Network 2,6,10-Trimethylpentadecane Detections
D-173	Task 4/44 GC/MS Analysis Network Bis(2-Ethylhexyl)phthalate Detections
D-174	Task 4/44 GC/MS Analysis Network Caprolactam Detections
D-175	Task 4/44 GC/MS Analysis Network Chlorobenzene Detections
D-176	Task 4/44 GC/MS Analysis Network Cyclopentanone Detections

VOLUME II LIST OF FIGURES (Continued)

D-177	Task 4/44 GC/MS Analysis Network Hexadecanoic Acid Detections
D-178	Task 4/44 GC/MS Analysis Network N-Eicosane Detection
D-179	Task 4/44 GC/MS Analysis Network N-Heneicosane Detections
D-180	Task 4/44 GC/MS Analysis Network N-Heptadecane Detections
D-181	Task 4/44 GC/MS Analysis Network N-Itexadecane Detections
D-182	Task 4/44 GC/MS Analysis Network N-Nonadecane Detections
D-183	Task 4/44 GC/MS Analysis Network N-Pentadecane Detections
D-184	Task 4/44 GC/MS Analysis Network Octadecane Detection.s
D-185	Task 4/44 GC/MS Analysis Network Tetradecane Detections
D-186	Task 4/44 GC/MS Analysis Network Octadecanoic Acid Detections
D-187	Task 4/44 GC/MS Analysis Network Tetrachloroethylene Detections
D-188	Task 4/44 GC/MS Analysis Network Tetrahydrofuran Detections
E-1	Contaminant Migration Distances in Selected Pathways

VOLUME III

APPENDIX F DETAILED DESCRIPTION OF ENVIRONMENTAL SETTING AND CONTAMINANT DISTRIBUTION

APPENDIX F TABLE OF CONTENTS

	PAGE
1.0 INTRODUCTION	1-1
1.1 Site Background	1-4
1.2 Nature and Extent of the Problem	1-5
1.3 Previous Investigations and Program Development History	1-5
1.4 Overview of Recent Investigation	1-8
2.0 ENVIRONMENTAL SETTING	2-1
2.1 Introduction	2-1
2.1.1 Location	2-1
2.1.2 Physiography	2-1
2.1.3 Vegetation, Climate and Land Use	2-1
2.2 Geology	2-3
2.2.1 Regional Geologic Setting	2-3
2.2.2 Regional Hydrogeologic Setting	2-4
2.2.3 Stratigraphy	2-5
2.2.3.1 Introduction	2-5
2.2.3.2 Description of Units	2-9
2.2.3.2.1 Denver Formation	2-9
2.2.3.2.2 Quaternary Deposits	2-16
2.2.4 Structures	2-20
2.2.4.1 Folds	2-20
2.2.4.2 Faults	2-20
2.2.4.3 Fractures	2-22
2.2.5 Geologic History	2-22
2.3 Surface Water	2-25
2.3.1 Local Hydrogeologic Setting	2-25
2.3.2 Surface Water Monitoring Systems	2-28

APPENDIX F TABLE OF CONTENTS (Continued)

	PAGE
2.3.2.1 Streamflow	2-31
2.3.2.2 Lake Levels	2-36
2.3.2.3 Precipitation and Evaporation	2-37
2.3.2.4 Utilities	2-38
2.3.3 Water Balance Results	2-38
2.3.3.1 First Creek Drainage	2-39
2.3.3.2 Irondale Drainage	2-39
2.3.3.3 Basins A and F Drainage	2-41
2.3.3.4 Sand Creek Lateral and Northwest Drainages	2-42
2.4 Groundwater	2-42
2.4.1 Introduction	2-42
2.4.1.1 Previous Investigations	2-42
2.4.1.2 General Features	2-43
2.4.1.3 Objectives and Methods	2-44
2.4.2 Denver Aquifer	2-45
2.4.2.1 Geologic Characteristics	2-45
2.4.2.2 Hydraulic Characteristics	2-46
2.4.2.3 Recharge	2-50
2.4.2.4 Denver Aquifer Movement	2-51
2.4.2.5 Discharge	2-53
2.4.3 Unconfined Flow System	2-53
2.4.3.1 Geologic Characteristics	2-53
2.4.3.2 Hydraulic Characteristics	2-57
2.4.3.3 Unconfined Flow System Recharge	2-64
2.4.3.4 Unconfined Flow System Movement	2-70
2.4.3.5 Unconfined Flow System Discharge	2-72
2.4.3.6 Vadose Zone	2-74
2.4.4 Interactions Between Surface and Groundwater	2-74
2.4.4.1 Upper Derby Lake	2-75
2.4.4.2 Lower Derby Lake	2-76
2.4.4.3 Ladora Lake and Lake Mary	2-78
2.4.4.4 Havana Pond	2-80
2.4.4.5 Basin A Drainage - Basin A	2-81
2.4.4.6 Basin A Drainage - Basins B, C, D, and E	2-85
2.4.4.7 Basin F	2-89
2.4.4.9 Sewage Treatment Plant	2-92

APPENDIX F TABLE OF CONTENTS (Continued)

	PAGE
2.4.4.10 First Creek and North Bog	2-93
3.0 SAMPLING AND ANALYSIS PROGRAMS AT RMA	3-1
3.1 Methods of Investigation	3-1
3.2 Sampling Programs	3-2
3.2.1 Historical Sampling Programs	3-2
3.2.1.1 360° Monitoring Program	3-3
3.2.1.2 Basin F Monitoring Program	3-3
3.2.1.3 North and Northwest Boundary Systems Monitoring	3-3
3.2.1.4 Irondale Boundary Control System Monitoring	3-4
3.2.1.5 U.S. Engineer Waterways Experiment Station Regional Monitoring Program	3-4
3.2.2 Recent Sampling Programs	3-4
3.2.2.1 Task 4 RMA Water Quantity/Quality Survey	3-6
3.2.2.2 Task 25 - North and Northwest Boundary System Monitoring	3-6
3.2.2.3 Task 36 - North Boundary System Component Remedial Action Assessment	3-6
3.2.2.4 Task 38 - Western Tier Trichloroethylene Investigation	3-7
3.2.2.5 Task 39 - Off-post Remedial Investigation	3-7
3.2.2.6 Task 44 - Regional Groundwater Monitoring	3-7
3.2.2.7 Shell South Plants Monitoring Program	3-7
3.3 Analytical Programs	3-8
3.3.1 Historic Analytical Parameters	3-8
3.3.2 Recent Program Analytical Parameters	3-12
4.0 NATURE AND EXTENT OF CONTAMINATION	4-1
4.1 Surface Water Quality	4-1
4.2 Groundwater Quality	4-14
4.2.1 Investigative Approach	4-17
4.2.1.1 Unconfined Denver Formation Wells	4-17
4.2.1.2 Hydrogeologic Controls on Plume Configuration	4-20
4.2.1.3 Data Presentation	4-20
4.2.1.4 Contouring Criteria	4-27
4.2.1.5 Identification of Major Contaminant Pathways	4-34
4.2.2 Dieldrin	4-34
4.2.2.1 Historical Water-Quality Data	4-35

APPENDIX F TABLE OF CONTENTS (Continued)

	PAGE
4.2.2.3 Denver Aquifer	4-41
4.2.3 Endrin	4-42
4.2.3.1 Historical Water Quality Data	4-42
4.2.3.2 Unconfined Flow System.	4-43
4.2.3.3 Denver Aquifer	4-47
4.2.4 Dithiane and Oxathiane	4-47
4.2.4.1 Historical Water Quality Data	4-48
4.2.4.2 Unconfined Flow System.	4-49
4.2.4.3 Denver Aquifer	4-52
4.2.5 Benzothiazole	4-53
4.2.5.1 Historical Water Quality Data	4-53
4.2.5.2 Unconfined Flow System.	4-54
4.2.5.3 Denver Aquifer	4-56
4.2.6 Organosulfur Compounds (chlorophenylmethyl sulfide, chlorophenylmethyl sulfoxide, and chlorophenylmethyl sulfone)	4-57
4.2.6.1 Historical Water Quality Data	4-58
4.2.6.2 Unconfined Flow System.	4-59
4.2.6.3 Denver Aquifer	4-63
4.2.7 Volatile Aromatic Organics Compounds	4-64
4.2.7.1 Total Volatile Aromatic Organic Compounds	4-64
4.2.7.2 Benzene	4-68
4.2.7.3 Chlorobenzene.	4-73
4.2.8 Volatile Halogenated Organics	4-79
4.2.8.1 Total Volatile Halogenated Organics	4-80
4.2.8.2 Chloroform	4-85
4.2.8.3 Trichloroethylene	4-90
4.2.8.4 Tetrachloroethylene	4-95
4.2.9 DBCP	4-100
4.2.9.1 Historical Water-Quality Data	4-100
4.2.9.2 Unconfined Flow System.	4-101
4.2.9.3 Denver Aquifer	4-104
4.2.10 Dicyclopentadiene	4-105

APPENDIX F TABLE OF CONTENTS (Continued)

	PAGE
4.2.10.1 Historical Water-Quality Data	4-106
4.2.10.2 Unconfined Flow System.	4-107
4.2.10.3 Denver Aquifer	4-110
4.2.11 Diisopropylmethyl Phosphonate	4-111
4.2.11.1 Historical Water Quality Data	4-111
4.2.11.2 Unconfined Flow System.	4-112
4.2.11.3 Denver Aquifer	4-117
4.2.12 Arsenic	4-118
4.2.12.1 Historical Water-Quality Data	4-119
4.2.12.2 Unconfined Flow System.	4-119
4.2.12.3 Denver Aquifer	4-122
4.2.13 Fluoride	4-123
4.2.13.1 Historical Water Quality Data	4-124
4.2.13.2 Unconfined Flow System.	4-125
4.2.13.3 Denver Aquifer	4-129
4.2.14 Chloride	4-134
4.2.14.1 Historical Water Quality Data	4-134
4.2.14.2 Unconfined Flow System.	4-135
4.2.14.3 Denver Aquifer	4-140
4.3 Gas Chromatography/Mass Spectrometry Results	4-144
4.3.1 Well Selection	4-145
4.3.2 GC/MS Analytical Methods	4-145
4.3.3 Quality Assurance/Quality Control.	4-150
4.3.4 Confirmation of Target Analytes and Concentrations	4-154
4.3.5 Nontarget Compound Analytical Results	4-155
4.3.5.1 Uncertainties in Nontarget Identification	4-155
4.3.5.2 Nontarget Compound Identification.	4-156
4.3.5.3 Nontarget Compound Occurrence and Distribution.	4-157
4.3.6 GC/MS Conclusions	4-160

APPENDIX F LIST OF TABLES

	PAGE
Table 1.0-1 RI Tasks That Included Assessments of Water Data	1-2
Table 2.2-1 Nomenclature Comparison for the Denver Formation at RMA	2-7
Table 2.2-2 Wells/Borings with Sandstones in Contact	2-8
Table 2.2-3 Sandstone Occurrence in Denver Zones 5 Through 9	2-11
Table 2.2-4 Zone B Sandstone Occurrence	2-17
Table 2.3-1 Control Structures and Gaging Locations	2-30
Table 2.3-2 RMA Lake Staff Gage Data (in ft)	2-32
Table 2.3-3 Characteristic Flow Statistics for Stream Gaging Stations at RMA	2-34
Table 2.3-4 RMA Monthly Water Balance Summary	2-35
Table 2.4-1 Summary of Results for Pumping Tests in the Denver Formation	2-48
Table 2.4-2 Summary of Hydraulic Conductivity (K) of Denver Fm Zones	2-49
Table 2.4-3 Areas of Potential Hydrologic Interaction Between Sandstones in the Denver Fm	2-54
Table 2.4-4 Alluvial Slug Tests Using the Bouwer-Rice Method	2-61
Table 2.4-5 Summary of Hydraulic Conductivity Estimates	2-62
Table 2.4-6 Sources of Recharge to the Unconfined Aquifer	2-65
Table 2.4-7 Calculated Hydraulic Gradients	2-71
Table 2.4-8 1986 and 1987 Water-Level Data for South Lakes Wells	2-77
Table 2.4-9 1986 and 1987 Water-Level Data for Basin A Wells	2-83
Table 2.4-10 1986 and 1987 Water-Level Data for Basin B	2-86
Table 2.4-11 1986 and 1987 Water-Level Data for Basin C	2-88
Table 2.4-12 1986 and 1987 Water-Level Data for Basin F	2-91
Table 3.2-1 Summary of 1985 to 1987 RMA Sampling Programs	3-5

APPENDIX F LIST OF TABLES (Continued)

	PAGE
Table 3.3-1 Target Analyte Lists for Tasks 25, 36, 38, 39 and 44	3-10
Table 4.1-1 Surface Water Sampling Sites and Sample Representation	4-3
Table 4.1-2 Surface Water Analyte Detections, Spring 1987	4-6
Table 4.1-3 Complete Organic Analyte Detections in Surface Water from Fall 1985 Through Fall 1987	4-9
Table 4.1-4 Arsenic Detections in Surface Water From Fall 1985 Throu Fall 1987	4-12
Table 4.2-1 Third Quarter FY87 Groundwater Sampling Network	4-15
Table 4.2-2 Comparison of CRL ¹ by Laboratory (ug/l) ²	4-18
Table 4.2-3 Unconfined Denver Wells and Designation Justification	4-21
Table 4.2-3 Unconfined Denver Wells and Designation Justification	4-22
Table 4.2-4 Presentation of Third Quarter FY87 Data	4-24
Table 4.2-5 Analyte Summary for the Alluvium, Unconfined Denver Fm and Confined Denver Fm, Third Quarter FY87	4-28
Table 4.2-6 Summary of Analytical Results for Dieldrin for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm	4-36
Table 4.2-7 Summary of Analytical Results for Endrin for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm	4-44
Table 4.2-8 Summary of Analytical Results for Composite Dithiane/Oxathiane for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm	4-50
Table 4.2-9 Summary of Analytical Results for Benzothiazole for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm	4-55
Table 4.2-10 Summary of Analytical Results for Composite Organosulfurs for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm	4-60
Table 4.2-11 Summary of Analytical Results for Benzene for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm	4-70
Table 4.2-12 Summary of Analytical Results for Chlorobenzene for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm	4-75

APPENDIX F LIST OF TABLES (Continued)

	PAGE
Table 4.2-13 Summary of Analytical Results for Chloroform for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm	4-87
Table 4.2-14 Summary of Analytical Results for Trichloroethylene for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm . . .	4-92
Table 4.2-15 Summary of Analytical Results for Tetrachloroethylene for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm . . .	4-97
Table 4.2-16 Summary of Analytical Results for DBCP for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm	4-102
Table 4.2-17 Summary of Analytical Results for DCPD for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm	4-108
Table 4.2-18 Summary of Analytical Results for Diisopropylmethyl Phosphonate for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm	4-113
Table 4.2-19 Summary of Analytical Results for Arsenic for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm	4-120
Table 4.2-20 Summary of Analytical Results for Fluoride for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm	4-126
Table 4.2-21 Summary of Analytical Results for Chloride for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm	4-136
Table 4.3-1 List of Wells from which Water Samples were Collected and Submitted for GC/MS Analysis	4-146
Table 4.3-2 GC/MS Target Analytes	4-151
Table 4.3-3 Certified Reporting Limits for Target Analytes	4-152

APPENDIX F LIST OF FIGURES

		PAGE
1.1-1	Location Map of Rocky Mountain Arsenal	1-11
1.3-1	Location of Basins, Containment Systems, Lakes, Chemical Sewers, Cultural Features, and Select Surface Features at RMA.	1-12
1.4-1	SAR Location Map.	1-13
1.4-2	RMA Groundwater Monitoring Tasks Study Areas.	1-14
2.1-1	Monthly Mean Temperatures With Mean Maximum and Minimum Ranges for the RMA Vicinity.	2-97
2.1-2	Monthly Total Snowfall and Precipitation for Stapleton Airport.	2-98
2.1-3	Estimated Blaney - Criddle Evapotranspiration and Cherry Creek Lake Evaporation Values.	2-99
2.2-1	Stratigraphic Column of the Denver Basin.	2-100
2.2-2	Upper Stratigraphic Sections of the Denver Basin	2-101
2.2-3	Structural Features of the Denver Basin Area	2-102
2.2-4	RMA Stratigraphic Column.	2-103
2.2-5	Thickness of Sandstone in Denver Zone 4	2-104
2.2-6	Thickness of Sandstone in Denver Zone 3	2-105
2.2-7	Thickness of Sandstone in Denver Zone 2	2-106
2.2-8	Thickness of Sandstone in Denver Zone 1	2-107
2.2-9	Thickness of Sandstone in Denver Zone 1u.	2-108
2.2-10	Thickness of Sandstone in Denver Zone A Emphasizing AL, AM, AS, and AU Sandstone Trends	2-109
2.2-11	Generalized East-West Cross Section From the South Platte River to the Northeast Corner of RMA	2-110
2.2-12	Quaternary Columnar Section.	2-111
2.2-13	Geologic Map of Rocky Mountain Arsenal Area	2-112

APPENDIX F LIST OF FIGURES (Continued)

	PAGE
2.2-14 Geological Interpretations for Part of Cross Section A-A'	2-113
2.2-15 Diagrammatic Depositional Environment of the Denver Fm at RMA	2-114
2.2-16 Bedrock Surface at RMA and Prominent Paleochannels	2-115
2.3-1 Infiltration Rates Associated With RMA Drainage Basins.	2-116
2.3-2 Surface Water Monitoring Site Locations	2-117
2.3-3 Surface Water Features and Alluvial Wells in the Vicinity of the Lower Lakes	2-118
2.3-4 Monthly Evaporation, Precipitation and Net Evaporation Values for the RMA Vicinity	2-119
2.3-5 Groundwater Elevation Projection Upon Centerline of Lower Lakes at RMA	2-120
2.4-1 Potentiometric Surface of the Unconfined Flow System, Third Quarter FY1987	2-121
2.4-2 Time Averaged Water Table Contour Map (1981-1987).	2-122
2.4-3 Locations of Denver Formation Aquifer Tests	2-123
2.4-4 Hydraulic Conductivity Histogram, Slug Tests in Denver Sands	2-124
2.4-5 Direction of Vertical Hydraulic Gradients Between Alluvial/Unconfined and Denver Wells at Cluster Sites.	2-125
2.4-6 Potentiometric Surface of Denver Zone 4, 3rd Quarter FY1987	2-126
2.4-7 Potentiometric Surface of Denver Zone 3, 3rd Quarter FY1987	2-127
2.4-8 Potentiometric Surface of Denver Zone 2, 3rd Quarter FY1987	2-128
2.4-9 Potentiometric Surface of Denver Zone 1, 3rd Quarter FY1987	2-129
2.4-10 Potentiometric Surface of Denver Zone 1U, 3rd Quarter FY1987	2-130
2.4-11 Potentiometric Surface of Denver Zone A, 3rd Quarter FY1987	2-131
2.4-12 Direction of Vertical Hydraulic Gradients Between Denver Wells at Cluster Sites.	2-132
2.4-13 Areas of Potential Denver Zone Sandstone Interaction	2-133
2.4-14 Base of the Unconfined Flow System	2-134

APPENDIX F LIST OF FIGURES (Continued)

	PAGE
2.4-15 Saturated Thickness Map For Unconfined Flow System.	2-135
2.4-16 Saturated Thickness of the Alluvial Material.	2-136
2.4-17 Location of Hydrographic Profiles and Well Locations for Seasonal Hydrographs	2-137
2.4-18 Seasonal Water Level Fluctuations for Wells Near North First Creek	2-138
2.4-19 Hydrographic Profile Upgradient of the NBCS (Line A-A')	2-139
2.4-20 Hydrographic Profile Through Sections 23 and 24, Across the NBCS (Line B-B')	2-140
2.4-21 Hydrographic Profile Upgradient of the NWBCS (Line C-C')	2-141
2.4-22 Hydrographic Profile Through NWBCS (Line D-D')	2-142
2.4-23 Seasonal Hydrographs for Wells 37308 and 37309.	2-143
2.4-24 1986 Seasonal Hydrograph for Well 37335.	2-144
2.4-25 Hydraulic Conductivity Histogram, Slug Tests in the Alluvium	2-145
2.4-26 Hydrogeologic Unit Map for Unconfined Flow System.	2-146
2.4-27 Lower Derby Lake Stage Loss Relationship Based on 1986 and 1987 Mass Balance Calculations.	2-147
2.4-28 Lake and Well Levels by Lakes Ladora and Mary	2-148
2.4-29 Pond Surface, Predicted and Observed Water Table Elevations With Monthly Precipitation for Havana Pond	2-149
2.4-30 Havana Pond Stage Loss Relationship Based on 1986 Weekly Mass Balance Calculations	2-150
2.4-31 Basins Location Map.	2-151
2.4-32 Lake and Well Levels by Uvalda Interceptor.	2-152
2.4-33 Sewage Treatment Plant Location and Associated Alluvial Well Locations.	2-153
2.4-34 First Creek Stream Bed Elevations Relative to Water Table Elevations.	2-154

APPENDIX F LIST OF FIGURES (Continued)

	PAGE
2.4-35 Comparison of First Creek Flows at the North and South Gages . . .	2-155
2.4-36 Estimated Groundwater Elevations Along First Creek From the Rocky Mountain Arsenal North Boundary to Highway 2	2-156
2.4-37 Comparison of First Creek Flows at RMA North Boundary and Highway 2	2-157
2.4-38 Change in First Creek Flows Off-post vs. Discharge at Highway 2 Station	2-158
2.4-39 Flow Frequency Histogram for First Creek at Highway 2 Station (July 1986 through August 1987)	2-159
4.1-1 Surface Water Quality Sample Sites at RMA	4-161
4.1-2 Spring 1987 Surface Water Compound Detections	4-162
4.1-3 Surface Water Quality Fall 85 - Fall 87 Multiple Detected Compounds.	4-163
4.2-1 RMA Contaminant Migration Pathways	4-164
4.2-2 Dieldrin Plumes Unconfined Groundwater Flow System, 3rd Quarter FY1987	4-165
4.2-3 Dieldrin Plumes Confined Denver Fm Zone I, 3rd Quarter FY1987. .	4-166
4.2-4 Endrin Plumes Unconfined Groundwater Flow System, 3rd Quarter FY1987	4-167
4.2-5 Dithiane/Oxathiane Plumes Unconfined Groundwater Flow System, 3rd Quarter FY1987	4-168
4.2-6 Dithiane/Oxathiane Composite Plumes Confined Denver Fm Zone I, 3rd Quarter FY1987	4-169
4.2-7 Benzothiazole Plumes Unconfined Groundwater Flow System, 3rd Quarter FY1987	4-170
4.2-8 Organosulfur Compounds (CPMS, CPMSO, CPMSO ₂) Plumes Unconfined Groundwater Flow System, 3rd Quarter FY1987	4-171
4.2-9 Summed Volatile Aromatic Plumes Unconfined Groundwater Flow System, 3rd Quarter FY1987.	4-172
4.2-10 Benzene Plumes Unconfined Groundwater Flow System, 3rd Quarter FY1987	4-173

APPENDIX F LIST OF FIGURES (Continued)

	PAGE
4.2-11 Benzene in Confined Portions of Denver Zones 2, 3, and 4 . . . . .	.4-174
4.2-12 Chlorobenzene Plumes Unconfined Groundwater Flow System, 3rd Quarter FY1987 . . . . .	.4-175
4.2-13 Chlorobenzene in Confined Portions of Denver Zones 2, 3 and 4 . . . .	.4-176
4.2-14 Summed Volatile Halogenated Organics Plumes Unconfined Groundwater Flow System, 3rd Quarter FY1987 . . . . .	.4-177
4.2-15 Chloroform Plumes Unconfined Groundwater Flow System, 3rd Quarter FY1987 . . . . .	.4-178
4.2-16 Trichloroethylene Plumes Unconfined Groundwater Flow System, 3rd Quarter FY1987 . . . . .	.4-179
4.2-17 Tetrachloroethylene Plumes Unconfined Groundwater Flow System, 3rd Quarter FY1987 . . . . .	.4-180
4.2-18 Dibromochloropropane Plumes Unconfined Groundwater Flow System, 3rd Quarter FY1987 . . . . .	.4-181
4.2-19 Dicyclopentadiene Plumes Unconfined Groundwater Flow System, 3rd Quarter FY1987 . . . . .	.4-182
4.2-20 Diisopropylmethyl Phosphonate Plumes Unconfined Groundwater Flow System, 3rd Quarter FY1987 . . . . .	.4-183
4.2-21 Arsenic Plumes Unconfined Groundwater Flow System, 3rd Quarter FY1987 . . . . .	.4-184
4.2-22 Fluoride Plumes Unconfined Groundwater Flow System, 3rd Quarter FY1987 . . . . .	.4-185
4.2-23 Fluoride Plumes Confined Denver Fm Zone A, 3rd Quarter FY1987 . .	.4-186
4.2-24 Fluoride Plumes Confined Denver Fm Zone 1U, 3rd Quarter FY1987 .	.4-187
4.2-25 Fluoride Plumes Confined Denver Fm Zone 1, 3rd Quarter FY1987 . .	.4-188
4.2-26 Fluoride Plumes Confined Denver Fm Zone 2, 3rd Quarter FY1987 . .	.4-189
4.2-27 Fluoride Plumes Confined Denver Fm Zone 4, 3rd Quarter FY1987 . .	.4-190
4.2-28 Fluoride Plumes Confined Denver Fm Zone 5, 3rd Quarter FY1987 . .	.4-191
4.2-29 Chloride Plumes Unconfined Groundwater Flow System, 3rd Quarter FY1987 . . . . .	.4-192

APPENDIX F LIST OF FIGURES (Continued)

	PAGE
4.2-30 Chloride Plumes Confined Denver Fm Zone A, 3rd Quarter FY1987 .	4-193
4.2-31 Chloride Plumes Confined Denver Fm Zone 1, 3rd Quarter FY1987. .	4-194
4.2-32 Chloride Plumes Confined Denver Fm Zone 2, 3rd Quarter FY1987. .	4-195
4.2-33 Chloride Plumes Confined Denver Fm Zone 3, 3rd Quarter FY1987. .	4-196
4.2-34 Chloride Plumes Confined Denver Fm Zone 4, 3rd Quarter FY1987. .	4-197
4.3-1 Task 4/44 Sampling Network and Wells Selected For GC/MS Analysis.	4-198

VOLUME IV

APPENDIX G

**COMMENTS AND RESPONSES TO THE WATER REMEDIAL
INVESTIGATION, DRAFT FINAL REPORT (VERSION 2.2) MARCH 1989**

APPENDIX G TABLE OF CONTENTS

	PAGE
U.S. Environmental Protection Agency Comments and Responses	G-1
Shell Oil Company Comments and Responses	G-25
Colorado Department of Health Comments and Responses	G-81

VOLUME V

LIST OF PLATES

- Plate 1 Hydrogeologic Cross-Section A-A'
- Plate 2 Hydrogeologic Cross-Section C-C'
- Plate 3 RMA Unconfined Flow System Sampling Network, 3rd Quarter FY87
- Plate 4 RMA Confined Denver Formation Sampling Network, 3rd Quarter FY87
- Plate 5 Thickness of Alluvial and Eolian Deposits
- Plate 6 Alluvial Deposits in Contact With the Bedrock Surface
- Plate 7 Elevation of the Bedrock Surface and Three Dimensional Bedrock Surface Map
- Plate 8 B-B' Cross Section
- Plate 9 Denver Formation Subcrop Map
- Plate 10 Elevation of Base of Lignite C
- Plate 11 Third Quarter FY87 Water Table Contour Map
- Plate 12 Time Averaged Water Table Contour Map (1981-1987)
- Plate 13 Saturated Thickness of Alluvial Material
- Plate 14 Base of the Unconfined Aquifer
- Plate 15 Saturated Thickness Map for the Unconfined Flow System
- Plate 16 Hydraulic Conductivity Map of Unconfined Flow System
- Plate 17 Location of Cross-Sections A-A', B-B' and C-C'

ACRONYMS AND ABBREVIATIONS

ac-ft	acre-feet
ac-ft/mo	acre-feet per month
ac-ft/yr	acre-feet per year
ACL	alternative concentration limit
Al	A lithologic zone - lower
Am	A lithologic zone - middle
ARAR	Applicable or Relevant and Appropriate Requirement
Army	Department of the Army
As	A lithologic zone - channel
ASTM	American Society for Testing and Materials
ASY	apparent specific yield
atm-m ³ /mole	atmosphere-cubic meter per mole
Au	A lithologic zone - upper
AWQC	ambient water quality criteria
1,2DCLE	1,2 dichloroethane
BTZ	benzothiazole
CC	Contamination Control
CCC	Colorado Climate Center
CCl ₄	Carbon Tetrachloride
CDH	Colorado Department of Health
CDM	Camp Dresser & McKee, Inc.
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CF&I	Colorado Fuel and Iron
cfs	cubic feet per second
CH ₂ Cl ₂	Methylene Chloride
cm/sec	centimeters per second
CMP	Comprehensive Monitoring Program
COE	U.S. Army Corps of Engineers
CPMS	chlorophenylmethyl sulfide
CPMSO	chlorophenylmethyl sulfoxide
CPMSO ₂	chlorophenylmethyl sulfone
CRL	certified reporting limits

ACRONYMS AND ABBREVIATIONS (Continued)

CSU	Colorado State University
CSU-GWFlow	Colorado State University Groundwater Flow Model
CWP	Composite Well Program
CWQ	Clean Water Act
DBCP	Dibromochloropropane
11DCE	1,1-dichloroethylene
11DCLE	1,1-dichloroethane
12DCE	trans-1,2-dichloroethylene
DCPD	Dicyclopentadiene
DIMP	Diisopropylmethyl phosphonate
1,4-DITH	1,4-dithiane
DMDS	dimethyldisulfide
DMMP	dimethylmethyl phosphonate
DOJ	Department of Justice
EA	Endangerment Assessment
EDL	elevated detection limit
EPA	U.S. Environmental Protection Agency
ESE	Environmental Science and Engineering, Inc.
FCP	First Creek Paleochannel
Fm	Formation
FRICO	Farmer's Reservoir and Irrigation Company
FS	Feasibility Study
ft	feet
ft/day	feet per day
ft/ft	feet per foot
ft/sec	feet per second
ft/yr	feet per year
ft ³	cubic feet
FY87	Fiscal Year 1987
gal/ft ²	gallons per square foot
GB	nerve gas comprised of Sarin
GC	gas chromatograph
G/ml	gram per milliliter
GC/MS	gas chromatography/mass spectrometry
WRI.TOC	
06/02/89	

ACRONYMS AND ABBREVIATIONS (Continued)

gpd/ft	gallons per day per foot
gpm	gallons per minute
H	Henry's Law Constant
HCCPD or CL ₆ CP	hexachlorocyclopentadiene
HGU	Hydrogeologic unit
HLA	Harding Lawson Associates
HSL	Hazardous Substance List
ICAP	inductively-coupled argon plasma
ICS	Irondale Containment System
ID	inside diameter
in/hr	inches per hour
in/mo	inches per month
IRA	Interim Response Action
ISP	Initial Screening Program
K	hydraulic conductivity
K _{oc}	organic carbon partition coefficient
K _d	partition coefficient
K _{ow}	octanol/water partition coefficient
LA	Lignite A
LB	Lignite B
lbs/ft ³	pounds per cubic foot
LC	Lignite C
LD	Lignite D
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
mg/l	milligrams per liter
mi	miles
MIBK	methylisobutyl ketone
MKE	Morrison-Knudsen Engineers, Inc.
mm	millimeter
mph	miles per hour
msl	mean sea level
NBCS	North Boundary Containment System

ACRONYMS AND ABBREVIATIONS (Continued)

NBTP	North Boundary Treatment Plant
NBW	north boundary west
NTC	nontarget compounds
NWBCS	Northwest Boundary Containment System
NWBP	Northwest Boundary Paleochannel
O&M	operation and maintenance
O ₃	ozone
PAS	Parties and the State
OCP	organochlorine pesticide
OD	outside diameter
°F	degrees Fahrenheit
OXAT	oxathiane
OX/DITH	Combined oxathiane and dithiane
PCE	tetrachloroethylene
PI	plasticity index
PID	photoionization detector
PMO-RMA	U.S. Army Program Manager's Office for Rocky Mountain Arsenal Contamination Cleanup
PMSO	Program Manager Staff Office
p,p'-DDE	p,p'-1,1-dichloro-2,2-bis(4-chlorophenyl)-ethylene
p,p'-DDT	p,p'-dichlorodiphenyltrichloroethane
PPLV	Preliminary Pollutant Limit Value
ppm	parts per million
psi	pounds per square inch
PVC	polyvinyl chloride
QA1	Paleochannels in terrace gravels
QA2	Paleochannels in eolian deposits (w/gravels)
QA3	Silty terrace gravels and coarse sand
QA4	Paleochannels in eolian deposits (w/o gravels)
QAE	Eolian deposits
QA/QC	Quality Assurance/Quality Control
QC	Quality control
QT	Quaternary terrace gravels
RCI	Resource Consultants, Inc.

ACRONYMS AND ABBREVIATIONS (Continued)

RCRA	Resource Conservation and Recovery Act
R _f	Retardation factor
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
RIC	RMA Information Center
RMA	Rocky Mountain Arsenal
RMACCPMT	Rocky Mountain Arsenal Control Management Team
ROD	Record of Decision
SACWSD	South Adams County Water and Sanitation District
SAR	Study Area Report
SARA	Superfund Amendments and Reauthorization Act
SCC	Shell Chemical Company
SCS	Soil Conservation Service
SDWA	Safe Drinking Water Act
Shell	Shell Chemical Oil Company
SO ₂	Sulfur Dioxide
sq mi	square mile(s)
STP	Sewage Treatment Plant
SW/GW	surface water/groundwater
T	transmissivity
111TCE	1,1,1-trichloroethane
112TCE	1,1,2-trichloroethane
TCLEE	tetrachloroethylene
TIC	tentatively identified compounds
TKd	Denver Formation
TRCLE	trichloroethylene
TSP	total suspended particulates
1u	number one upper zone in the Denver Fm
ug/g	micrograms per gram
ug/l	micrograms per liter
UFS	Unconfined Flow System
UNK	unknown
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency
USCS	Unified Soil Classification System

WRI.TOC
06/02/89

ACRONYMS AND ABBREVIATIONS (Continued)

UTM	Universal Transverse Mercator
VC	volcaniclastic interval
VCE	clay-rich zone stratigraphically equivalent to VC
VOA	volatile organic aromatics
VOC	volatile organic compounds
VOH	volatile organohalogens
WES	U.S. Army Corps of Engineers Waterways Experiment Station
WRI	Water Remedial Investigation
WY87	Water Year 1987

1.0 INTRODUCTION

The purpose of the Water Remedial Investigation is to present the U.S. Department of the Army's Remedial Investigation results for the RMA on-post water media. This document is a formal Remedial Investigation product prepared in accordance with the Federal Facility Agreement (1989), the RMA Technical Program Plan (TPP) (Program Manager's Offices PMO, 1988 RIC#88131R01) and the June 1985 Remedial Investigation Guidance Document (U.S. Environmental Protection Agency, EPA). This report is one of four Remedial Investigation reports and seven Remedial Investigation Study Area Reports (SARs) prepared to define the nature and extent of contamination and complete a comprehensive Remedial Investigation for the On-post Operable Unit of RMA as required by the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), as amended by the Superfund Amendments and Reauthorization Act (SARA) and the National Contingency Plan (NCP). The Water Remedial Investigation is a compilation, integration and interpretation of ground and surface water data obtained from specific tasks designed to provide a comprehensive assessment of contaminant occurrence at the site. This report was prepared under contract number DAAK11-84-D-0016 and represents volume 6 of the overall RMA Remedial Investigation document. Tasks involved in collecting and evaluating water data under the RMA Remedial Investigation programs are listed in Table 1.0-1. All tasks were completed in September, 1988. Acronyms used in this report are identified after the Table of Contents.

The report provides a general overview of contamination in water at RMA. It is not intended to be the only source of information for the Feasibility Study. The USATHAMA database, and other detailed investigations also are appropriate sources of information.

The RMA environmental setting is evaluated in terms of:

- o Geology;
- o Hydrology;
- o Nature and extent of water-borne contamination; and
- o Contaminant pathway analyses.

The results of these evaluations were integrated to provide a comprehensive understanding of contaminant occurrence at the site.

Table 1.0-1 RI Tasks That Included Assessments of Water Data
(Page 1 of 2)

Task Number	Name	Media	Contractor
1	Section 36	Soils	ESE
2	South Plants	Soil, Air, Buildings, Spills, Groundwater	Ebasco
4	RMA Water Quantity/Quality Survey	Ground and Surface Waters	ESE
6	Sections 26 & 35 - Phase I	Soils	ESE
7	Lower Lakes, Phase I Contamination Assessment	Soils, Sediments	Ebasco
11	Hydrazine Blending & Storage Facility Contamination Assessment	Soils, Water	Ebasco
12	Derby Lakes Phase I Contamination Assessment	Soils, Sediments	Ebasco
19	Phase II Survey Sections 26 & 35	Soils, Groundwater, Basin Fluids and Solids	ESE
20	Lakes Area - Phase II	Soil, Sediments, Waters	Ebasco
21	Army Sites North - Phase II Contamination Assessment	Soils	ESE
22	Army Sites South - Phase II Contamination Assessment	Soils	Ebasco
23	Overall Soils/Groundwater Integration	Soils, Groundwater	ESE
25	RMA Boundary Systems Monitoring	Groundwater	ESE
26	Basin A/Basin A Neck	Soils, Groundwater	Ebasco
35	Endangerment Assessment	N/A	Ebasco

Table 1.0-1 RI Tasks That Included Assessments of Water Data
(Page 2 of 2)

Task Number	Name	Media	Contractor
36	North Boundary System Component Response Assessment	Groundwater	ESE
38	Western Tier Trichloroethylene Study	Soils, Groundwater	Ebasco
39	Off-post RI/FS	Air, Soils/Sediments, Biota, Groundwater, Surface Water	ESE
42	North Plants Contamination Assessment	Soils, Groundwater, Spills	Ebasco
44	Groundwater/Surface Water Monitoring Program	Ground and Surface Waters	ESE
47	Supplementary Phase II Surveys on the Northern Sections of RMA	Soils, Waters, Air	ESE
48	Supplementary Phase II Surveys on the Southern Sections of RMA	Soils, Water	Ebasco
66	Off-post Remedial Investigation	Biota, Groundwater, Surface Water, Soils	ESE

Source: ESE, 1988.

1.1 Site Background

RMA occupies over 17,000 acres in Adams County, Colorado (Figure 1.1-1) and is located approximately 10 miles northeast of downtown Denver. Stapleton International Airport extends to the southern border of RMA. Surrounding land use includes residential, light industrial manufacturing and agricultural. Residential population in the vicinity is concentrated to the west with a population of approximately 1.5 million within 15 miles.

RMA was established in 1942 as a manufacturing facility for the production of chemical and incendiary munitions. Throughout World War II, chemical intermediate munitions, toxic end-item products and incendiary munitions were manufactured and assembled by the Army. From 1945 to 1950, stocks of Levinstein mustard were distilled, mustard-filled shells were demilitarized, and mortar rounds filled with smoke and high explosives were test-fired. Various obsolete ordnance were also destroyed by detonation or burning during this period.

In the early 1950's, RMA was selected to produce the chemical nerve agent GB (Sarin) under U.S. Army operations. The North Plants manufacturing facility was completed in 1953 and produced agents until 1957, with munitions-filling operations continuing until late 1969. The primary activities between 1969 and 1984 involved the demilitarization of chemical warfare materials.

Concurrent with military activities, industrial chemicals were manufactured at RMA by several lessees from 1947 to 1982. In 1947, portions of the site were leased to the Colorado Fuel and Iron Corporation (CF&I) and Julius Hyman & Company for chemical manufacturing of chlorinated benzenes, dichlorodiphenyltrichloroethane, naphthalene, chlorine and fused caustic. In late 1949, Julius Hyman & Company (Hyman) leased portions of the property previously covered by the CF&I lease. Shell Chemical Company acquired Julius Hyman & Company in 1952 and in 1954 replaced Hyman as lessee under the lease. Shell conducted manufacturing operations at the site until 1982. Manufactured products included pesticides (such as Akton, Aldrin, Azodrin, Clodrin, Dieldrin, Landrin, Nudrin, Parathion, Pydrin, Shellchlor, Supona and Vapona), herbicides (such as Atrazine, Bladex and Planavin), nematocides (such as dibromochloropropane (DBCP) and dichloropropenes-dichloropropanes (DD soil fumigant)), adhesives, anti-icers, curing agents, cutting oil additives, gear oil additives and lubricating greases.

Disposal practices at RMA have included routine discharge of industrial waste effluents to unlined evaporation basins and burial of solid wastes at various locations. Fluctuations in fluid disposal volumes influenced the groundwater regime by artificially recharging the hydrogeological system, locally raising the water-table ("mounding"), and impacting contaminant concentrations down-gradient. Unintentional spills of raw materials, process intermediates and end products have also occurred within the manufacturing complexes at RMA.

Crop damage north of RMA, as early as the mid-1950's, was eventually attributed to shallow groundwater contamination. In 1975, in response to the detection of offsite contaminants, the Colorado Department of Health issued Cease and Desist Orders. A regional sampling and hydrogeologic surveillance program was initiated as a result, requiring quarterly collection and analysis of over 100 on-post and off-post surface and groundwater samples. Since 1975, various programs have been implemented to monitor surface and groundwater in accordance with operational and regulatory requirements.

1.2 Nature and Extent of the Problem

Numerous investigations have determined that the occurrence of both on-post and off-post water-borne contamination, consisting of a variety of organic and inorganic parameters, is related to the past activities of the U.S. Department of the Army (Army), Shell and other industrial operators within the RMA boundaries. The number and types of contaminants analyzed in RMA groundwater have changed somewhat over time. Factors contributing to these changes include environmental and climatological variations, RMA activities and contaminant fate and migration history. Contaminants detected in RMA ground and surface waters include volatile halogenated organics, volatile aromatics, chlorinated pesticides, organosulfur compounds, chemical agent breakdown products, chloride, fluoride and arsenic.

1.3 Previous Investigations and Program Development History

Initial investigations at RMA were prompted by complaints from farmers with land adjacent to the northwestern boundary where severe crop losses resulted from the use of shallow well water for irrigation (Ralph M. Parsons Co., 1955, RIC#84192R06). The

farmers believed that their crops had been damaged by chemicals manufactured at RMA. The Ralph M. Parsons Company was contracted to prevent or decrease future groundwater contamination by chemicals from RMA. The company was also tasked with determining the presence of a toxic chemical in groundwater, identifying the chemical and recommending corrective procedures. According to this report, the presence of a toxic chemical was not firmly established and further work was recommended.

Figure 1.3-1 identifies significant features including disposal basins, plant facilities, and surface water features at the site. Waste from all operations conducted prior to 1956 were discharged north of the South Plants area into unlined Basin A, C, D, and E. Ralph M. Parsons Company studies prompted the construction of an asphalt lined disposal basin, Basin F. This basin was completed in 1956 and utilized in 1957. Subsequently, liquid industrial wastes were discharged into Basin F (Moloney, 1982, RIC#85085R01).

A number of studies were conducted at RMA between 1956 and 1974 in an attempt to define the hydrogeologic system and identify the toxic constituent(s) in ground and surface water. In May of 1974, diisopropylmethyl phosphonate and dicyclopentadiene were detected in surface water at the northern boundary. Later that year, CDH detected diisopropylmethyl phosphonate in a well north of the site. In April of 1975, CDH issued three administrative orders directed against Shell and/or the Army. These orders, referred to as the "cease and desist orders", directed Shell and/or the Army to:

- o Take steps, as necessary, to cease and desist from all unauthorized discharges to the waters of the State;
- o File an application for a discharge permit;
- o Establish a groundwater surveillance program;
- o Maintain monitoring and sampling records; and
- o Report the results of monitoring to the State.

As a result of the cease and desist orders, a Contamination Control Program was established in 1974 to ensure compliance with Federal and State environmental laws. Potential and actual contaminant sources were identified and migration pathways were delineated. To mitigate problems associated with contaminant migration off-post, three groundwater treatment systems were installed between 1978 and 1984 at the northern and northwestern property boundaries to intercept and treat contaminated groundwater and

reinject the treated water into the subsurface. Boundary containment system evaluation programs were initiated for: the North Boundary Containment System (containment system pilot plant, 1978; extended to full capacity, 1981); Irondale Containment System (1981); and the Northwest Boundary Containment System (1984). Specific sampling programs are discussed in Section 3.0.

Subsequent studies, directed by the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA), were conducted to identify, control and treat pollutants. These studies indicated that contaminants were concentrated mainly in the shallower alluvial groundwater. The contaminants apparently entered the groundwater system from a number of sources including: the group of disposal basins used to store liquid wastes; the chemical sewer; the South Plants area; and other manufacturing, storage, disposal, spill and leakage sites.

Groundwater flow direction and volumes in various geographical areas were studied by the U.S. Army Corps of Engineers Waterways Experiment Station under separate funding from USATHAMA. The U.S. Engineer Waterways Experiment Station studies identified areas where the alluvium is in direct contact with underlying permeable sandstones of the Denver Formation. This indicates that the basal alluvium and upper Denver Formation are locally in hydrogeologic communication and that the potential for contaminant transport avenues exists between them (May, 1982, RIC#82295R01).

The first overall data assessment was performed by Geraghty & Miller, Inc. in 1981 (Stollar and van der Leeden, 1981, RIC#81293R05) and a site-wide hydrogeologic study was recommended as a result of this assessment. This recommended study was performed by U.S. Engineer Waterways Experiment Station (May, 1982, RIC#82295R01). Since that time, more site-specific studies have been conducted in an effort to fill data gaps and to respond to specific questions about such topics as surface water quantity and quality and infiltration capacities of soils.

In 1982, contaminant source control strategies and assessment of the associated remediation costs were developed in the Contamination Control Program. The Source Control Report generated by the RMA Contamination Control Program Management Team (RMACCPMT) in 1983 delineated the procedures for the development of a contamination control strategy. The report documented the results of a 2.5 year study on potential

contamination control strategies that would ensure compliance with State and Federal statutes pertaining to the release of pollutants into the environment. The report also included an extensive technical review and analysis of migratory pathways of hazardous contaminants and their sources; an assessment of applicable environmental laws; development of corrective strategies with available technology; screening and evaluation of alternative strategies; and the selection of a preferred strategy.

The RMA Decontamination Report (RMACCPMT, 1984, RIC#84034R01) was developed by the Army for planning purposes. It identified and classified over 150 potential contamination sources and provided a preliminary assessment of the extent, probable use, boundaries and possible contamination profile of these sources. This report was developed based upon personnel interviews and upon the information contained in the Source Control Report (RMACCPMT, 1983, RIC#83326R01). No field verification was conducted for this report. The report also discussed environmental laws affecting decontamination activities and evaluated technical approaches for attaining decontamination.

1.4 Overview of Recent Investigation

As a result of the contamination at RMA two lawsuits were filed in December 1983. The first was brought by the State of Colorado against the United States and Shell for natural resource damages both on and off the site, and for response costs under CERCLA. The second was filed by the United States against Shell for response costs and for natural resource damage at RMA. The United States and Shell have entered into a Federal Facility Agreement and a Settlement Agreement that, among other things, established procedures for assessment, selection, and implementation of response actions resulting from the release or threatened release of hazardous substances at or from the Arsenal and set forth the terms and conditions for payment of response costs by the Army and Shell.

The Army created a separate office specifically to deal with the contamination problems at RMA. This office is referred to as the Program Manager's Office (PMO) for the Rocky Mountain Arsenal Contamination Cleanup. It awarded contracts to two consultant teams to define the nature and extent of contamination at the site and to provide litigation support data for the U.S. Department of Justice in relation to the lawsuits.

Task order contracts were developed for each consulting group. The general objectives of the task orders were to conduct an environmental program to define the nature and extent of contamination and to select remedial action alternatives to mitigate contamination problems. Survey elements included Remedial Investigation, Endangerment Assessment (EA) and the Feasibility Study (FS).

Air, biota, buildings, soil and water Remedial Investigation Reports have been prepared to assess contaminant occurrence and distribution within these media. The Air Remedial Investigation (ESE, 1988c, RIC#88263R01) assesses airborne contaminant occurrence and establishes ambient air quality conditions for RMA. The study concluded that, in general, there were no significant sources of airborne contaminants prior to the commencement of remedial measures at RMA.

The Biota Remedial Investigation studied the presence of contamination in plant and animal communities on RMA. As part of the program, biota were sampled for seven contaminants (aldrin, arsenic, dieldrin, endrin, dichlorodiphenyl trichloroethane, dichlorodiphenylethane and mercury). Preliminary results indicated that mercury and organochlorine pesticides were present in the lake ecosystems on RMA and that these chemicals were bioaccumulating in aquatic food chains. Detailed information on the results of biota contaminant analysis and an evaluation of adverse biological effects are provided in the Biota Remedial Investigation (ESE, 1989a, RIC#89054R01).

The Building Remedial Investigation (Ebasco, 1988e, RIC#88306R02) reviewed the history of all structures located at RMA and identified activities that occurred within these structures. A field program was undertaken to verify structure locations and to identify the volume of material comprising these structures. A limited sampling program was undertaken as part of the field program. Based on the above efforts, each structure was assigned a contamination classification.

Individual Contamination Assessment Reports (CARs), which assessed soil contamination, were prepared. CAR results were utilized in dividing RMA into several related study areas. In general, CAR sites within each study area share similar history and site characteristics. Chemical data and interpretations for both soil and water were integrated with geologic, hydrogeologic and source area assessments to comprehensively define contaminant sources, and their migration through soil and water in each study area.

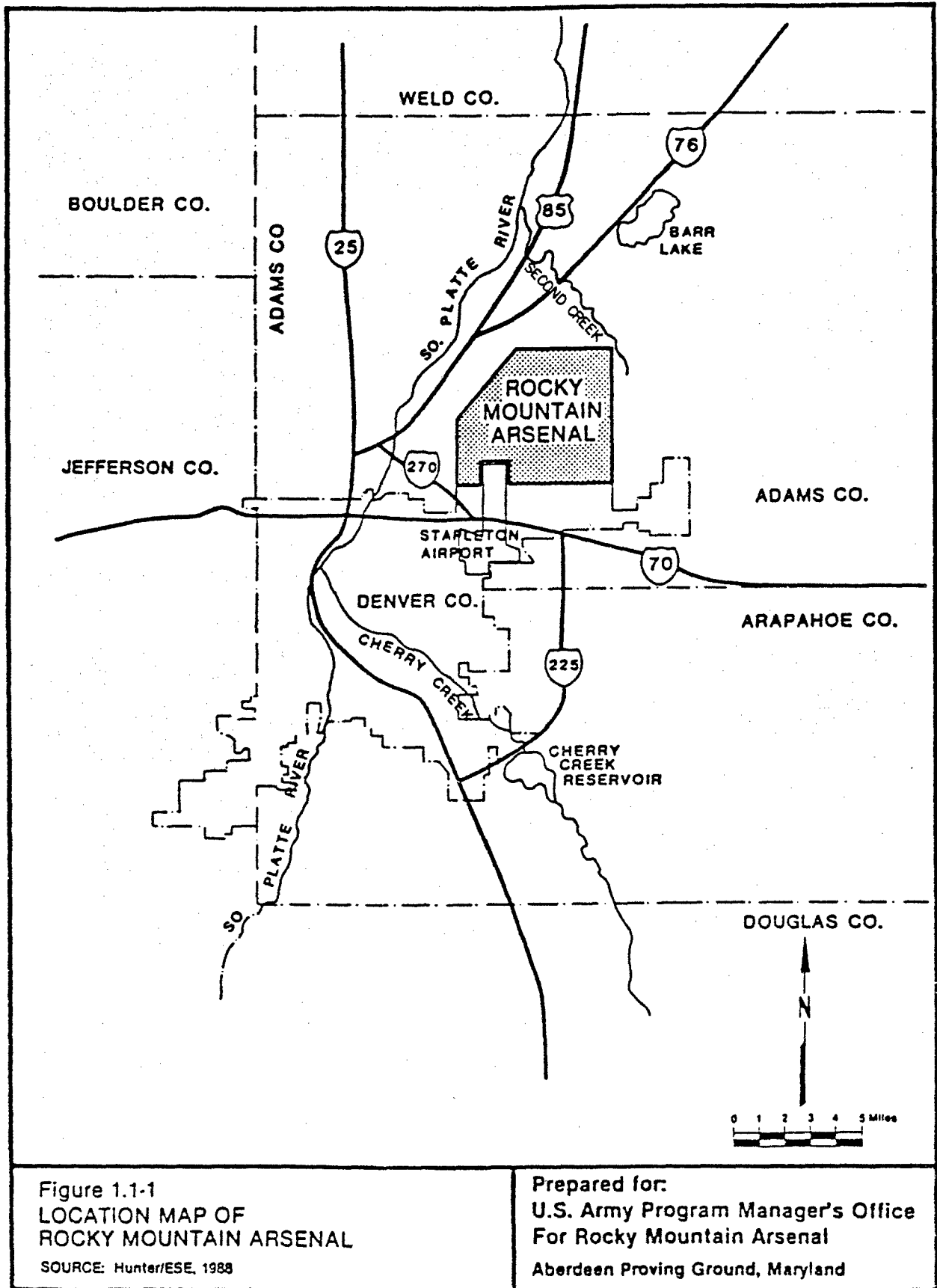
Results of these assessments are presented in Study Area Reports (SARs) (Figure 1.4-1).

Regional and site specific monitoring were conducted under Tasks 4, 25, 26, 36, 38, 39, 42 and 44. Data and results of Tasks 26, 38 and 42 are reported in the South Plants, Western and North Plants SARs, respectively. Results of Task 4, 25, 36 and 39 are presented in individual task reports. Task 44 evolved into the Water Remedial Investigation report. Information from these tasks and interpretations of individual SARs are incorporated in the geologic, hydrogeologic and contaminant distribution assessments in the Water Remedial Investigation report. Figure 1.4-2 shows the task study areas used to produce the Water Remedial Investigation report. The objective and scope of work associated with selected tasks are presented in Section 3.0.

Hydrogeologic monitoring at selected source areas was included as part of various soil investigation tasks. Under these efforts, water quality and hydraulic monitoring were performed at existing or newly installed groundwater wells in order to determine potential soil and/or water interactions. Activities as described were conducted under Tasks 1, 19, 21, 23 and others.

Shell has conducted both short and long term groundwater monitoring programs. Shell has an on-going quarterly sampling program of the DBCP plume, from the railyard to the Irondale Containment System initiated in 1981. In 1988 MKE/Shell performed a groundwater quality sampling program for the South Plants Area.

The Comprehensive Monitoring Program was developed as a post Remedial Investigation program to provide long term hydrologic information at RMA. This program was designed to provide both regional monitoring and site and/or source specific monitoring, as well as long-term hydrogeologic monitoring in both the on-post and off-post areas.



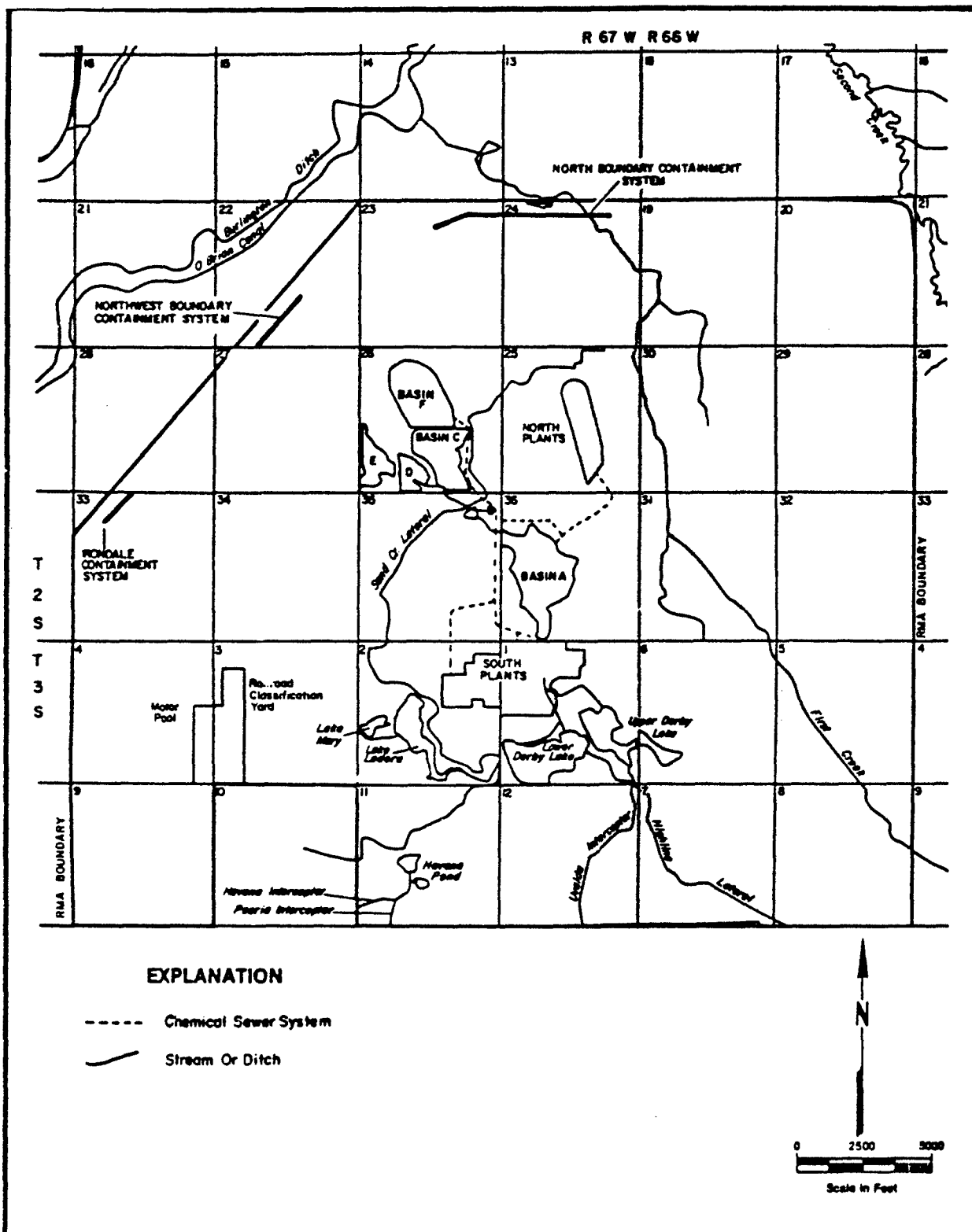
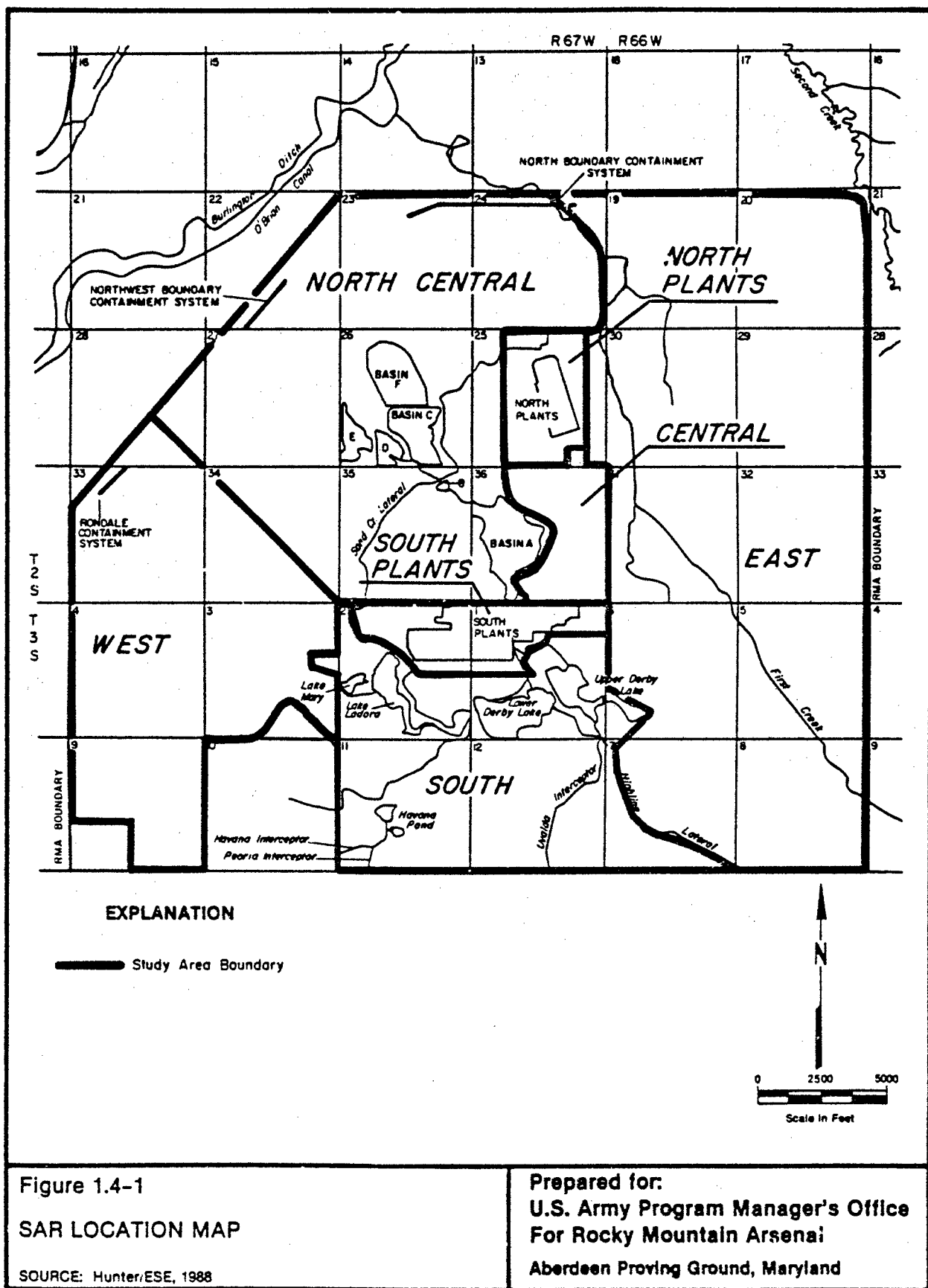
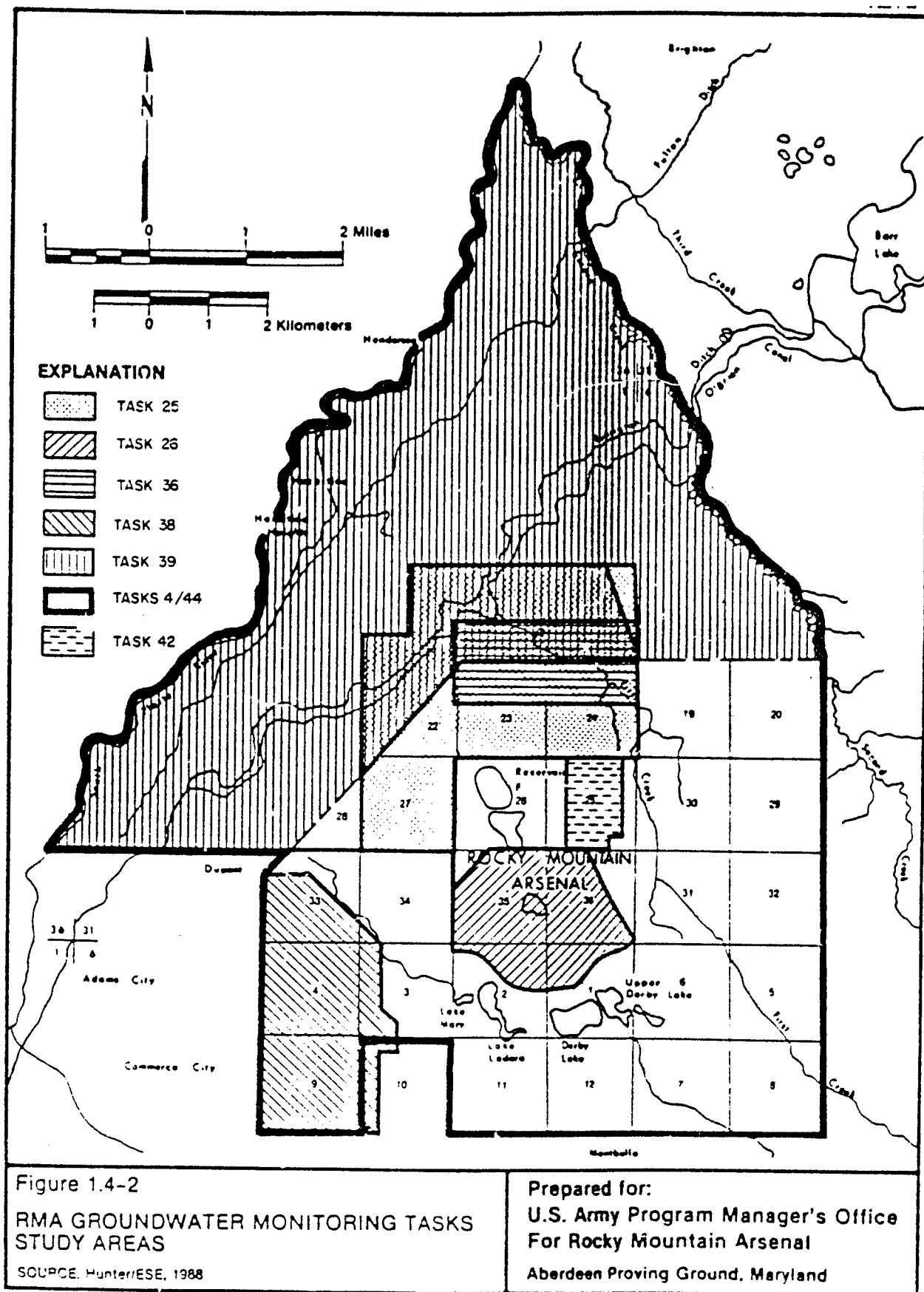


Figure 1.3-1

LOCATION OF BASINS, CONTAINMENT SYSTEMS,
LAKES, CHEMICAL SEWERS, CULTURAL FEATURES,
AND SELECT SURFACE WATER FEATURES AT RMA
SOURCE: Hunter/ESE, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland





2.0 ENVIRONMENTAL SETTING

2.1 Introduction

Contaminant distribution at RMA is strongly influenced by physiographic, geologic and hydrogeologic characteristics of the area. Section 2 describes these physical characteristics and provides a comprehensive review of the natural systems that control surface and groundwater contaminant distribution.

2.1.1 Location

RMA is located in Townships 2 and 3 South and Ranges 66 and 67 West. Commerce City, Montbello and Stapleton International Airport border the site on the west and south respectively. The north and east are bordered by farm and range land. Roads at RMA form a grid with 1 mile spacings corresponding to the section lines. Section numbers on RMA are unique, hence sections are referred to in this report by section number only.

2.1.2 Physiography

RMA is located in the High Plains physiographic province and is characterized by gently rolling hills. The topographic surface slopes from the southeast to the northwest. Total change in the land-surface elevation is 220 feet (ft) across the site. The site is located in the South Platte River drainage basin.

2.1.3 Vegetation, Climate and Land Use

Prior to establishment in 1942, much of RMA was irrigated farmland. Currently, the site supports a wide variety of biota. Shortgrass prairie and disturbed grasslands predominate in the northern part of RMA. Lakes, wetlands and woodlands in the southern areas provide cover, food, and reproductive habitat for animal species such as mule and white tail deer, prairie dog, badger, coyote, ring-necked pheasant, mourning dove, and a variety of birds of prey. Bald eagles, a federally designated endangered species, occupy the site for winter roosting and foraging. Additional information on the Biota are provided in the Biota Remedial Investigation Report (ESE, 1989a, RIC#89054R01)

Soil types have been identified for the area and are described in the USDA Adams County Soil Survey (Sampson, 1974, RIC#81266R54). Soil series present on site include the Ascalon, Blakeland, Nunn, Platner, Stoneham, Truckton, Vona, and Weld series. Other surficial materials identified by the survey are gravelly sand/shale outcrop complex, and loamy, sandy, and wet alluvial land. Detailed soil maps are presented in individual Study Area Reports.

Representative climatological and meteorologic information for RMA is provided by a National Weather Service station located two miles south of RMA at Stapleton International Airport. The average annual precipitation is 15.25 inches with a maximum recorded precipitation of 23.31 inches in 1967 and a minimum of 7.51 inches in 1954. Rainfall for 1986 and 1987 was 12.09 and 12.03 inches respectively. Fifty-one percent of the annual precipitation falls between April and July. Frequent summer thunderstorms cause significant variations in local precipitation. Most thunderstorms are of short duration, although weather fronts with upslope winds occasionally produce longer events. Runoff from abrupt, high-intensity thunderstorms contributes to the sharp peak flows observed in area stream channels. The average annual snowfall is 62.8 inches, which accounts for approximately 30 percent of the annual precipitation (Colorado Climate Center, 1988). Snow is present on the ground an average of 48 days.

The average annual temperature is 64.1° Fahrenheit (F) with a record high of 103°F and a low of -25°F. Figure 2.1-1 is a graph of monthly mean temperatures. There are approximately 93 days per year that have a cloud cover of 30 percent or less. The average monthly precipitation at Stapleton International Airport is 1.27 inches. The monthly maximum was 7.31 inches in May 1957, while the minimum was 0.01 inch which occurred in November 1949, January 1952, September 1956 and February 1970 (Figure 2.1-2) (CCC, 1988). Precipitation that occurs as snowfall may accumulate in the colder months and melt in early spring. The snowpack may release water into the soil during times which may not correspond to precipitation events. Average monthly total snowfall is highest in November and March and lowest in January. The snow season extends from September to May with an average snowfall depth of 7.0 in. mo.

Average monthly potential evaporation ranges from 0.53 in./mo in January to 6.80 in./mo in July. Average annual evaporation is 38.5 inches based on a 27 year average for Cherry Creek Reservoir (COE, 1987). Evapotranspiration values were estimated for pasture grass

using the Blaney-Criddle empirically-based equation and Stapleton International Airport climatic data. Evapotranspiration values, or consumptive use as referred to in the equation, closely parallel the evaporation curve with values from the equation being slightly lower. The evapotranspiration values range from 0.0 in/mo for January when the crop is dormant to a maximum of 7.00 in/mo for the month of July. Plots of Cherry Creek evaporation and the Blaney-Criddle estimated evapotranspiration are given in Figure 2.1-3.

Prevailing winds at RMA are from the south and southwest and average 9 miles per hour annually. The windiest months are March and April with gusts up to 65 mph (ESE, 1988c RIC#88263R01). Wind-formed surface depressions and natural basins exist in the central, northwestern, and southern areas of RMA.

2.2 Geology

2.2.1 Regional Geologic Setting

More than 10,000 ft of sediments have accumulated in the Denver Basin, including conglomerate, sandstone, siltstone, shale, claystone and limestone. A general geologic column for the area, including lithologic descriptions of Upper Cretaceous and Tertiary formations, is presented in Figure 2.2-1. Generalized cross-sections are shown in Figure 2.2-2.

RMA is located in the Denver Basin, an elongate, north-to-south trending asymmetric syncline with maximum dimensions of 300 miles by 200 miles. The basin extends from north of Cheyenne, Wyoming to south of Colorado Springs, Colorado and is divided into two parts by a structural ridge in the Greeley, Colorado area. The basin is bound on the west by the Colorado Front Range and on the south by a series of structural uplifts (Figure 2.2-3). Sedimentary deposits along the eastern flank of the basin are gently dipping, while those along the western flank are steeply dipping. RMA is located close to the north-south axis of the Denver Basin. The regional dip of the strata underlying the RMA is approximately one degree to the southeast.

The ancestral Denver Basin was formed in Pennsylvanian time (300 million years before present). When the basin was first formed, its center was located some 60 miles south of

Denver. Subsidence in the area continued sporadically throughout later history as evidenced by a predominance of marine sediments with interbedded continental and near-shore deposits. During the time represented by deposition in the basin, three distinct orogenic episodes (mountain building periods) occurred in the area that have influenced the depositional environment and structural development of the basin. In addition, glacial and interglacial periods were responsible for creating the environment that resulted in development of present-day topographic features and Quaternary sediments.

In Late Cretaceous time, prior to Laramide orogenic activity, shallow marine seas covered much of the interior North American continent. During much of Cretaceous time, thousands of feet of fine-grained sediment accumulated, resulting in the formation of the Pierre Shale. Laramide mountain building activity uplifted the Rocky Mountain Front Range and downwarped the Denver Basin. These events caused the sea to retreat southward and resulted in the deposition of continental sediments. Deposits in the Denver Basin, beginning with the Fox Hills Formation overlying the Pierre Shale, reflect this change in depositional environments from marine to continental. During Late Cretaceous and Early Tertiary time, the Laramie, Arapahoe and Denver Formations were deposited. The Denver Formation is continental in origin and represents fluvial and lacustrine depositional environments. Overlying the Denver Formation are unconsolidated Quaternary and Holocene alluvial and eolian deposits.

2.2.2 Regional Hydrogeologic Setting

The RMA site lies within the South Platte River drainage basin. The South Platte River is located west and northwest of RMA and is the major area stream. Perennial and intermittent tributaries flow into the South Platte River. The largest area tributary is Cherry Creek, located south of RMA (Figure 1.1-1). Intermittent and perennial springs also occur within the drainages.

Major bedrock aquifers in the Denver area are the sandstone of the Fox Hills Sandstone, Laramie, Arapahoe, and Denver Formations and Dawson Arkose (Figure 2.2-1). The Pierre Shale, underlying the Fox Hills Sandstone, is considered the base of the Denver Basin aquifer system due to its great thickness and minimal permeability (Robson and Romero, 1981, RIC#82350M02).

2.2.3 Stratigraphy

2.2.3.1 Introduction

Abundant information from numerous sources was utilized to characterize the geology at RMA. Lithologic and electric logs from over 1,000 monitoring wells and other borings were synthesized for subsurface characterization. Lithologic units were correlated, projected, and mapped throughout the entire on-post area using a database specifically developed to characterize the geology at RMA (MKE, 1988). The database was constructed from observations and results of previous investigations, studies by Morrison-Knudsen Engineers, Inc., (MKE) and Remedial Investigation and/or Feasibility Study tasks. Lithologic descriptions and stratigraphic relationships in the Denver Formation and overlying alluvium are presented below from oldest to youngest.

The Denver Formation at the RMA site is between 200 and 500 ft thick. (Figure 2.2-4). As much as 130 feet of Quaternary alluvial and eolian sediments (Plate 5) cover most of the RMA site (Lindvall, 1980). Alluvial deposits overlying the Denver Formation are shown on Plate 6.

Stratigraphic relationships within the Denver Formation are illustrated in Figure 2.2-4. The oldest horizon penetrated in deep borings at RMA probably is the Arapahoe Formation (MKE, 1988). This interpretation is based on a projection of the Denver-Arapahoe contact from off-post subsurface data and is subject to revision as new data become available. The Denver Formation is separated from the underlying Arapahoe Formation by a claystone interval informally named the Buffer Zone. MKE (1988) suggests that the Buffer Zone is 30 to 50 ft thick east of RMA.

Stratigraphic units of the Denver Formation dips approximately 1° to the southeast at RMA, while the bedrock surface slopes from southeast to northwest (Plate 8). Older zones are exposed in northern portions of RMA, while progressively younger zones were exposed to the southeast (Plates 1, 2, 8, 9). Subsurface data indicate that the Denver Formation zones strike north-northeast in the north-central portion of RMA, while apparent strike is more northerly in western portions of the RMA.

Stratigraphic zones in the upper Denver Formation, often capped by lignitic intervals, represent stacked fluvial point bar sequences composed of sandstone, siltstone, and claystone. The lignitic intervals in the upper section have some degree of lateral continuity and serve as marker beds across the site. Deeper horizons are less well known and correlations are uncertain. Sandstones are not generally laterally continuous and correlation between individual sandstones within any one zone is tenuous. Sandstones within any one zone, however, should be considered coeval (deposited at the same time), unless there is a clear stratigraphic relationship between them (e. g. vertically stacked sandstones with interbedded siltstone or claystone).

Informal nomenclature for the Denver Formation underlying the RMA is based upon stratigraphic relationship with the shallowest mappable lignite, designated Lignite A (LA) (Figure 2.2-4). Each point bar sequence and associated capping lignite are numbered or lettered sequentially with increasing depth, beginning with the zone immediately underlying Lignite A, "1U" (or 1 Upper), followed by Lignite B, Zone 1, Lignite C, Zone 2, Lignite D, and Zones 3 through 9. Zones overlying Lignite A are designated sequentially upward from Lignite A, beginning with Zone A. Overlying Zone A is a volcanoclastic interval, which is overlain by Zone B. Zone B is overlain by Quaternary sediments. Different nomenclature was previously designated informally by MKE (1988) and ESE (1988e, RIC#88344R02). The nomenclature designated by this report supercedes previous designations. Table 2.2-1 shows the correlation between the previous designations.

Zones are usually separated by lignitic intervals, however, erosion may have locally removed claystones and lignites prior to deposition of an overlying zone. In these areas where finer-grained layers separating sandstones in different zones are reduced in thickness, sandstones from different zones may be in contact. This may occur between Zones 2 and 3 in the vicinity of the North Boundary Containment System and Zone 1 and 2 in areas in Sections 25 and 26. Additionally, Unit AS (sandstone of Zone A) appears to have incised the underlying Lignite A in the western portion of Section 25, the southeast corner of Section 36 and the northern portion of Section 26, thereby reducing the vertical separation between Zone A and Zone 1U sandstone in these areas. Table 2.2-2 lists wells and borings in which sandstones are in contact with each other.

Sandstones have been identified in Zones A through 4 and occur in Sections 1, 2, 23, 24, 35, and 36 at RMA (Figures 2.2-5 through 2.2-10). These sandstones, deposited in the

Table 2.2-1 Nomenclature Comparison for the Denver Formation at RMA*

This Report	MKE	Task 36 Report
A Zone	--	--
Lignite A	Unit 7500	--
1U	Units 7300-7400	--
1	Units 7300-7400	--
2	Units 7200-7300	NBW#1A, NBW#1, NBE#1
3	Units 7100-7200	NBW#2, NBE#2
4	Unit 7100	NBW#3
5-7	Unit 7100	--
8-9	Buffer Zone	--

* Comparisons are generalized; individual wells may vary.

Source: ESE, 1988.

Table 2.2-2 Wells/Borings with Sandstones in Contact

Well/Boring Number	Denver Fm Sandstone Zones in Contact
24142/143	Sandstones in zones 3 and 4
25037	Sandstones in zones 1 and 2
26132	Sandstones in zones 1 and 2
35032	Sandstones in zones 1u and 1
35068	Sandstones in zones 1 and 2
36069/105	Sandstones in zones Al and Am
36114	Sandstones in zone 1 and 2
36148/149/150	Sandstones in zones 1 and 2
36179	Sandstones in zones 1 and 2
37387	Sandstones in zones 2 and 3
995	Sandstones in zones 3 and 4

Source: ESE, 1988.

same general location through time, exhibit similar north-to-south trends and are interpreted to reflect a recurring depositional pattern resulting in stratigraphically stacked point bar sequences.

Alluvial deposits unconformably overlie the eroded surface of the Denver Formation. Stratigraphic relationships between alluvial deposits are complex. As in typical terrace deposits, older alluvial units occupy higher stratigraphic positions than younger units. A generalized cross-section through the northwest corner of RMA (Figure 2.2-11) illustrates these relationships. Although the Verdos Alluvium (Figure 2.2-12) is the oldest alluvial deposit at RMA, isolated erosional remnants are preserved on paleohighs (Figure 2.2-11). The Slocum Alluvium occurs on two benches cut into bedrock by the South Platte River in the northwest and western portions of RMA (Plate 6). MKE (1988) has mapped the older Slocum Alluvium on the upper bench and the younger Slocum Alluvium on the lower bench, closer to the river. The Louviers Alluvium occurs stratigraphically below the older Slocum Alluvium and unconformably overlies bedrock benches adjacent to the South Platte River. Locally, post-Louvier channel-fill events occurred that incised the alluvium and underlying bedrock in Section 26 and east of the South Platte River. The coarse-grained Broadway Alluvium, overlying the Louviers Alluvium, may subcrop beneath the western and southwestern portions of RMA (Plate 6). The Broadway Alluvium is exposed 1/2 mile northwest of the site.

Loess/eolian deposits are the predominant surficial sediments at RMA (Figure 2.2-13). These deposits unconformably overlie weathered Denver Formation bedrock on the eastern half of RMA and older alluvial deposits on the western half. The Piney Creek and Post Piney Creek Alluvial deposits overlie loess/eolian deposits and are the youngest alluvial deposits at the site. They represent recent floodplain deposits of the South Platte River.

2.2.3.2 Description of Units

2.2.3.2.1 Denver Formation

The Upper Denver Formation is informally divided into 17 zones (Figure 2.2-4) described below:

Zones 5 Through 9

Zone 9 is the basal interval defined for the purposes of this study. Zone 5 underlies Zone 4. Zones 5 through 9 are less well known than shallower zones. Table 2.2-3 lists wells and borings at RMA interpreted to have penetrated these zones.

Zones 5 through 9 are generally predominated by finer-grained sediments, and generally contain less than 50 percent sandstone. Finer-grained sediments in these zones consist primarily of claystones with siltstone lenses. The claystones are described as sandy or silty or both, dark olive gray, hard to soft, carbonaceous and blocky. Lignitic intervals of varying thicknesses cap most zones. Sandstones in Zones 8 and 9 are medium- to fine-grained, silty, fairly- to poorly-sorted, gray, moderately to poorly cemented and laminated. Zone 7 consists of interbedded sandstone, siltstones, and claystones (55 percent sandstone). The sandstones are quartzitic, fine-grained, clayey, fairly- to poorly-sorted, olive gray, hard, well cemented, carbonaceous and micaceous. Sandstone composition in Zone 6 varies, but in general consists of quartzose sandstones that are fine- to medium-grained, moderately- to well-sorted, occasionally silty to clayey, gray to green gray, hard to soft, well- to poorly- cemented, occasionally micaceous and laminated. Sandstone in Zone 5 is quartzitic, generally medium-grained with rare clayey intervals, generally well-sorted, olive gray, hard, well cemented, calcareous, and occasionally contains lignitic seams.

Data for Zones 5 through 9 are limited and sandstone thickness maps have not been prepared. However, Zone 9 sandstones are less than 5 ft of the total zone thickness of 20 ft, while Zones 7 and 8 may have greater than 20 ft thick sandstone in a total of 30 and 40 ft, respectively. Zone 6 sandstones are generally less than 10 ft of a total of 30 ft, while Zone 5 sandstones are approximately 10 ft thick of a total 25 ft.

Zone 4

Zone 4 lies between Zones 3 and 5. Sandstones are interpreted to be continuous in Sections 22, 23, and 24 (Figure 2.2-5). Finer-grained sediments in this zone consist of claystones which are typically greenish to dark gray, blocky and massive to crumbly. Siltstones are clayey, dark gray and hard. The sequence is overlain by a partially eroded lignitic interval. Sandstone descriptions are based on information from the north-northwest and western portions of RMA.

Table 2.2-3 Sandstone Occurrence in Denver Zones 5 Through 9

Well/ Boring Number	Sandstone Zone	Sandstone Top (elevation MSL)	Sandstone Base (elevation MSL)	Net Sandstone Thickness (ft)
03007	7	5008.0	5005.0	3.0
04009	5	5044.0	5039.0	5.0
04012	5	5040.0	5036.0	4.0
04012	6	5032.0	5009.0	23.0
22002	5	5018.0	5001.0	17.0
22031	5	5020.0	5006.0	14.0
23210	5	5022.4	5010.4	12.0
23210	6	5000.6	4978.4	20.2
23210	8	4956.4	4929.4	27.0
23401	5	5025.0	5017.0	8.0
26137	5	4995.0	4994.0	1.0
26137	6	4974.0	4959.0	8.0
27055	5	5026.0	5015.0	11.0
28025	5	5042.0	5026.0	16.0
28026	6	5024.0	5018.0	1.0
28029	5	5057.0	5038.0	17.0
33027	5	5066.0	5047.0	19.0
33027	6	5034.0	5027.0	7.0
33029	7	5020.0	5016.0	4.0
33029	8	4990.0	4980.0	7.0
33031	6	5007.0	4999.0	8.0
33032	7	4988.0	4970.0	8.0
33035	5	5050.0	5046.0	4.0
975	5	5022.4	5018.4	4.0
975	6	4998.4	4988.4	7.0
975	7	4954.4	4952.4	2.0
975	8	4934.4	4932.4	2.0
975	9	4871.4	4869.4	2.0
995	5	0	0	0
995	6	0	0	0
995	7	4978.0	4961.0	17.0
995	8	4930.0	4928.0	2.0
995	9	4899.0	4893.0	6.0
EP-19	5	5026.0	5017.0	9.0

Source: ESE, 1988.

Sandstones in Zone 4 are quartzitic, generally fine- to medium-grained, clayey or silty, fairly- to poorly-sorted, green gray to dark gray, hard, well cemented to uncemented, calcareous and carbonaceous. Sandstones in Section 23 occasionally contain rounded clay clasts. Most Zone 4 sandstones are graded.

Zone 4 is up to 50 ft thick with sandstones greater than 30 ft thick. A net sandstone isopach map is shown in Figure 2.2-5.

Zone 3 and Lignite D

Zone 3 overlies Zone 4 and underlies Lignite D. Sandstones trend north-to-south through Sections 26 and 35 and northeast-to-southwest through Sections 23 and 24 (Figure 2.2-6). Lateral continuity between Zone 3 sandstones is difficult to establish. Finer-grained sediments consist of greenish claystone layers that are hard, blocky and crumbly. These claystone layers are silty in places, though siltstone as a separate unit is rarely described. Lignite D consists of interbedded lignite and organic shale. It consists of gray shale, organic shale and lignites. In Zone 3, sandstone intervals consist of quartz sandstone that is very fine-to medium-grained, silty with clay, moderately- to poorly-sorted, greenish gray to dark gray, and generally uncemented to poorly cemented. Zone 3 is 45 ft thick. Sandstones are up to 33 ft thick, while Lignite D ranges from less than 1 to 13 ft thick with an average thickness of 3 ft. A net sandstone isopach map for Zone 3 is shown in Figure 2.2-6.

Zone 2 and Lignite C

Extensive data are available to characterize Zone 2. Zone 2 sediments overlie Lignite D and underlie Lignite C. Sandstones exhibit general northwest-to southeast trends (Figure 2.2-7). Sandstones are interpreted to be interconnected in the southern portion of Section 26. Sandstones near the North Boundary area are less laterally continuous and isolated sandstones are present in Sections 9 and 25. Finer-grained sediments consist primarily of claystones which are dark gray to gray, hard and thinly bedded with a blocky and crumbly texture. Siltstones are generally clayey and dark gray with occasional claystone laminae. Lignite C, interbedded between Zones 1 and 2, is predominantly a lignite with lateral facies changes to organic shale. Sandstone characteristics are varied, however intervals generally consist of quartz sandstones that are fine- to medium-grained, silty with clay layers in thinner sandstones, greenish gray to gray, cemented to

uncemented, with rare organic and micaceous material. The sandstones are massive to thinly bedded and may be better sorted in areas of thicker sandstones.

Zone 2 is approximately 55 ft thick with sandstones up to 41 ft thick. Lignite C is less than 1 ft to 13 ft thick with an average thickness of 5 ft. Figure 2.2-7 is the net sandstone isopach for the zone.

Zone 1 and Lignite B

Data from north and central portions of RMA are available to assess sandstone occurrences in Zone 1. Zone 1 is interbedded between the underlying Lignite C and overlying Lignite B. The sandstones exhibit generally north-to-south trends at the site (Figure 2.2-8). They occur near the central portions of Sections 25 and 26, thinning to the west and south. Sandstone also occurs in Section 30 and may or may not be laterally continuous with those in Sections 25 or 26. Finer-grained sediment consists mainly of claystones which are dark gray, dark blue gray or light tan in color and are hard to brittle. Siltstones, present in lesser amounts, are clayey and brownish gray to dark gray in color. Lignite B, interbedded between Zones 1U and 1, changes facies laterally to lignitic, carbonaceous, organic claystone. Zone 1 contains quartz sandstones that are very fine- to medium-grained, silty, well- to poorly-sorted, light gray, light yellow, and yellow brown in color, uncemented to well cemented, hard, and may be micaceous. Sandstones in this interval contain oxidized zones or intervals. Where sandstones are thick, they may be massive and better sorted. Where sandstones are relatively thin, they tend to be thinly bedded.

Zone 1 is up to 60 ft thick with sandstones up to 54 ft thick. Lignite B ranges in thickness from less than 1 ft to 12 ft, with an average thickness of 5 ft. Figure 2.2-8 is the net sandstone isopach for the zone.

Zone 1U and Lignite A

Zone 1U, overlying Lignite B and underlying Lignite A, is assessed from data available from the central portions of RMA. Sandstone occurs in Sections 1 and 35 and trends northwest-to-southeast. Associated thinner sandstones occur along distally along channel margins (Figure 2.2-9). Sandstones are interpreted to extend into Sections 25 and 30, although lateral continuity is uncertain. Finer-grained sediments in this zone consists predominantly of shales which are gray to dark gray, hard to moderately hard, thinly

bedded and have a blocky texture and occasional scattered, silty sand lenses. Siltstones are sandy and clayey, dark gray and have a trace of organic material. Lignite A, the principal marker bed at the site, overlies Zone 1U and underlies Zone A. It is predominantly a lignite with interbedded organic shale. Sandstones in the Zone 1U are generally thinner than sandstones in deeper zones. They are fine- to medium-grained, silty and clayey, moderately- to poorly-sorted, light green gray to olive gray, and generally well cemented. The sandstones may contain lenses of claystone and siltstones, and may be massively or thinly bedded.

Figure 2.2-9 is a net sandstone isopach for Zone 1U. Sandstones comprise up to 36 ft of the 40-ft thick unit. Lignite A ranges between 2 and 11 ft thick with an average of 6 ft.

Zone A

Zone A overlies Lignite A and underlies the volcanoclastic zone. Sandstones in Zone A, originally defined by May (1983, RIC#83299R01), were designated Unit AS. Zone A sandstones have been redefined as Unit AL, for the basal sandstone, Unit AM for the middle sandstone, and Unit AU for the upper sandstone. This designation now takes precedence over May's nomenclature.

Unit AS is stratigraphically equivalent to Units AM and AL. The sandstones are associated with a north-to-south trending paleochannel first identified by May. The paleochannel system, present Sections 1, 2, 35, and 36, is approximately 2,500 ft wide and with accumulated sandstones up to 45 ft thick (Figure 2.2-10). Thinner channels occur in Unit AL and exhibit a north-to-south trend through Section 35 and a northwest to southeast orientation in Section 36. Unit AS also is mapped in Section 25 and the southeast corner of Section 26. A thick interval of Unit AL sandstone occurs in Section 6, but data to assess its lateral continuity are limited.

Finer-grained sediments within these units consist primarily of claystones which are dark gray, well compacted, generally uncemented and micaceous, with low to high organic content and blocky texture. Lignites are sometimes present and may occur as thin lenses within the claystones. Sandstone is interbedded with siltstones, claystones and lignitic claystones. Units AS and AL are quartzitic, fine- to coarse-grained and well- to poorly-sorted, with angular to subrounded grains. The sandstones are slightly micaceous.

Although calcite cement is present at the top of the unit, most of the sandstones are uncemented. Sandstones in Units AL, AM, and AU are medium-grained with thin, interlayered siltstones and sandy claystones, and angular to subrounded sand grains. They are generally partially consolidated and uncemented. Organic content may be appreciable, and mica is usually present.

Zone A is up to 75 ft thick and sandstones are commonly 5 to 10 ft thick with a maximum thickness in excess of 40 ft. The net sandstone isopach for Zone A is shown in Figure. 2.2-10.

Zone VC

A volcanoclastic interval, identified as Zone VC (May, 1982, RIC#82295R01 and 1983, RIC#83299R01), overlies Zone A (Figure 2.2-4). The zone occurs in the central, eastern, and southeastern portions of RMA.

Zone VC is difficult to characterize due to its heterogeneous nature. The unit is highly bentonitic and contains fresh to altered volcanoclastic materials in a poorly bedded or disturbed matrix. Volcanoclastic material most commonly consists of sand- to cobble-sized lithic fragments that are angular to subangular, poorly sorted, dense and occur in a silt- to clay-rich bentonitic matrix. Devitrified ash fragments, lapilli grains, disaggregated amphiboles, pyroxenes, quartz and feldspar occur in the matrix. The freshly exposed unit is gray to greenish gray and brown, reddish brown or yellowish brown on weathered surfaces.

Interbedded fluvial sandstones and claystones also occur within the zone and are referred to as Unit VCE. Claystones, laterally equivalent to the volcanoclastic material, are described as olive, dark brown or dark gray in color and hard with a blocky or crumbly texture. Sandstones, in places interbedded with claystones, are very fine-grained, silty, olive colored, firm, and thinly bedded.

Zone VC is approximately 50 ft thick with volcanoclastic deposits measuring between 10 and 35 ft thick. An isopach map has not been prepared for this zone.

Zone B

Zone B sandstones occur within the central and southeastern parts of the site and are discontinuous. Thicker sandstones are found in Sections 35 and 36, while thinner sandstones have been identified in Sections 5, 7, 8, and 11. Finer-grained sediment in Zone B consists of claystones which are silty, sandy, olive or olive gray and blocky and crumbly in texture. Sandstones within Zone B are fine- to coarse-grained, gray, poorly- to well-sorted and hard to soft. Sandstones may contain sandy claystone layers, claystone lenses and organic inclusions.

Due to the discontinuous nature of Zone B, an isopach was not prepared. The zone is up to 25 ft thick with sandstones in excess of 10 ft thick. Elevations and thicknesses are listed in Table 2.2-4.

2.2.3.2.2 Quaternary Deposits

Surficial deposits, composed of both alluvium and eolian deposits, are collectively referred to as alluvium or alluvial deposits for the purposes of this discussion.

Verdos Alluvium

The Verdos Alluvium (Kansan age), the oldest alluvial unit at RMA, unconformably overlies the weathered bedrock surface of the Denver Formation. Erosion during the Yarmouth interglacial period removed most of the Verdos Alluvium; however, isolated remnants are preserved on topographic highs in Sections 19 and 25 (Figure 2.2-11; Plate 6; MKE, 1988). Distribution of specific alluvial units and relationships between bedrock and overlying alluvial sequences are illustrated in Plate 6 and Figure 2.2-13.

The Verdos Alluvium is light brown to reddish brown, poorly sorted, stratified gravel with lenses of clay, silt, sand and thin beds of white volcanic ash. Possible paleosol horizons are characterized by calcium carbonate-rich zones in the upper part of the unit. The thickness of the unit is up to 20 ft (Lindvall, 1980). Verdos Alluvium was once used as a source of sand and gravel at RMA (Lindvall, 1983).

Table 2.2-4 Zone B Sandstone Occurrence

Well/ Boring Number	Sandstone Top (elevation MSL)	Sandstone Base (elevation MSL)	Net Sandstone Thickness (ft)
05003	5225	5222	3
07004	5184	5182	2
08004	5216.3	5208.6	7.7
11003	5179.9	5170.3	9.6
35055	5250.4	5231.4	19.0
36155	5243.3	5231.3	12.0

Source: ESE, 1988.

Slocum Alluvium

The Slocum Alluvium, deposited in two pulses separated by a brief erosional episode during Illinoian time, occurs on bedrock benches adjacent to the South Platte River (MKE, 1988). This unit is also present over large areas of Sections 22, 23, 24 and 26 and along the boundary between Sections 34 and 35 (Plate 6).

The Slocum Alluvium is silty sand and gravel with brown to reddish-brown, well-stratified pebbly clay. Cobbles and boulders are scattered throughout the unit (Lindvall, 1983). The Slocum Alluvium does not outcrop at RMA, but is commercially exploited for sand and gravel in the Sand Creek drainage, three miles south of the site. The alluvium has a composite thickness of approximately 40 to 45 ft.

Louviers Alluvium

Glaciation during early Wisconsin time led to deposition of the coarse-grained Louviers Alluvium. Regional correlations suggest that the unit may have been much thicker and more laterally extensive prior to erosion. The upper, finer-grained sequences were stripped by erosion, preserving only the lower, coarser-grained sediments at the site. In the South Platte River paleodrainage northwest of RMA, headward erosion left isolated, localized remnants of the Louviers Alluvium. The alluvium is really extensive in upper tributaries of the South Platte River, beyond the limits of headward erosion (Trimble and Machette, 1979). At RMA, the Louviers unconformably overlies the Denver Formation throughout much of Sections 4, 28, 33 and 34 (Plate 6). An unconformable alluvial unit, identified by MKE (1988) as unit ID 8950, was formed by erosion of older alluvium and subsequent infilling of the South Platte River tributary paleochannels.

The Louviers Alluvium is a reddish to yellowish-brown, coarse-grained, arkosic sand with rare cobble, pebble, silt and clay lenses. Silt and clay lenses exhibit cross-bedding or contorted bedding (Lindvall, 1980). Louviers Alluvium is a major source of sand and gravel in the South Platte River drainage. At RMA, this unit ranges from 5 to 20 ft thick.

Broadway Alluvium

The gravelly Broadway Alluvium, of middle Wisconsin age, was deposited following Louviers time. The Broadway was deposited along fluvial channels of the South Platte River paleodrainage, and generally becomes coarser-grained to the west (Hansen and Crosby,

1982). Outcrops of this unit occur along the eastern floodplain of the South Platte River from Littleton to Commerce City. At RMA, the Broadway Alluvium occurs in Sections 3, 9, 27, and 34 (Plate 6).

The Broadway Alluvium is a pink to light-brown, generally well-stratified sand and gravel unit occupying well-defined terraces on the east side of the South Platte River (Lindvall, 1980). The uppermost section consists of fine-grained silts and clays. The Broadway Alluvium is also a major source of sand and gravel in the South Platte River drainage and ranges up to 30 ft thick.

Loess/Eolian Deposits

Loess/Eolian deposits of Late Wisconsin and Early Holocene time are widely distributed at RMA (Figure 2.2-13) and unconformably overlie older alluvium and weathered bedrock (Plate 6). Lindvall (1983) has recognized a sequence of loess deposits (wind-blown deposits of angular silt-sized particles) that are exposed near the Second Creek Drainage, east of the site. The loess is interpreted to be the oldest eolian deposit at RMA. Eolian sands overlie the loess and cover most of the site.

Loess is a yellowish to light-grayish brown sandy silt, with appreciable amounts of clay. The eolian material consists of light-brown, fine-grained sand, sandy silt and clay. Loess mapped off-post has thicknesses up to 20 ft, although on-post thicknesses are generally less than 10 ft. Eolian sands, generally range in thickness from 10 to 20 ft. Locally, sand thickness of 40 to 50 ft occur where formerly incised channels have been infilled (Lindvall, 1983).

Piney Creek and Post Piney Creek Alluvium

The Piney Creek Alluvium is a thin fluvial deposit found along active South Platte River tributaries. Both First Creek and Second Creek occupy channels that are in-filled with fine-grained Piney Creek Alluvium (Figure 2.2-11). The youngest alluvium in the South Platte River system is the Post Piney Creek Alluvium. This unit represents the floodplain deposits of the larger streams and is not present within the site boundaries. The Piney Creek and Post Piney Creek Alluvium, which consist of sand, silt and clay with local basal channel lag deposits of gravel, are 5 to 10 ft thick.

2.2.4 Structures

Structurally, the site is influenced by its position within the Denver Basin. Proximity to the structural axis and low regional dip to the southeast results in weakly developed local structural features. Folds, faults and fractures are discussed below.

2.2.4.1 Folds

Apparent structural features are revealed by structure contour maps constructed on the base and top of lowermost sandstones within Zones A through 4 and on the base of Lignites A, B, C, and D. Many of these features, however are attributed to erosion and differential compaction. Consistent generalized structural trends are apparent in most of the maps and show the Denver Formation generally dipping to the southeast. Dip based on the Lignite C marker (Plate 10) is approximately 35 ft per mile (0.4 degrees).

Several geologic models or hypotheses have been developed to explain the geologic setting in Sections 25, 26, and 35. Possible interpretations are shown in Figure 2.2-14. The general interpretation has been accepted for this report. This feature is best expressed by the structure contour map of Lignite C (Plate 10). A possible structural high, illustrated by structure maps constructed on the base of sandstone in Zones A, 1, 2, and 3, may be enhanced by the effects of differential compaction and by the data distribution.

2.2.4.2 Faults

Faults have been extensively studied at the site to determine their presence within the Denver Formation. A database, consisting of previous site-specific and regional investigations, was compiled and compared with recent investigations. Previous investigators addressing aspects of structural geology relevant to the site include, but are not limited to, Emmons et al (1896), DeVoto (1968, RIC#84291R01), Weimer (1973, RIC#81266R59), Miller et al (1979) and Kirkham and Rogers (1981). These investigations provide a basis for comparison with recent studies and are briefly described below.

Emmons et al (1896) did not indicate any faults in the area now occupied by RMA; however, most of the work is based on limited outcrops and no subsurface data. Post-

Denver depositional movement is suggested by the study in areas considerably north of the site.

DeVoto's work (1968, RIC#84291R01) involves a study of Quaternary deposits displaying features possibly either fault-related or developed by geomorphic processes. This study did not find definitive evidence of faulting.

The existence of basement faults beneath the site is documented by Evans (1965, RIC#81356R32), although they are not believed to extend into the uppermost Cretaceous section. Weimer's study (1973, RIC#81266R59), although more regional in extent, supports this interpretation. His study indicates that recurrent movement along basement-controlled faults influenced sedimentation during the Late Cretaceous, but did not find significant offset in Late Cretaceous sediments across the Cherry Creek fault. Based on these data he suggests that, "...a fault break could not have extended from the basement to the uppermost Cretaceous (an interval of approximately 11,000 ft)". Weimer's study also found that maximum movement took place along north-northwest trending regional faults, although minor faults having northeast and southeast trends were noted.

Earthquake potential maps for the State of Colorado, prepared by Kirkham and Rogers (1981), confirm deep, basement controlled faults, but do not definitively identify faults in Cretaceous or Tertiary age rocks.

In 1979, Miller et al investigated a small dike located on Rattlesnake Hill in Section 35. The dike was studied using seismic and petrographic techniques. Petrographic data are too limited to ascertain whether or not the dike is of igneous origin and Miller et al conclude that the dike is of probable clastic origin. Clastic dikes are formed by various sedimentary processes unrelated to faulting.

Since 1981, a number of organizations, including U.S. Army Corps of Engineers Waterways Experiment Station, ESE, Ebasco, Todd and Associates, MKE, and R. L. Stollar and Associates, have been involved in characterizing site geology and hydrogeology. Most investigators initially felt that faults exist at RMA because of the difficulty in identifying and correlating subsurface stratigraphic units across the site. Numerous wells were drilled in locations where faults were suspected and cross-sections constructed. These studies indicate that faulting is unlikely; however, the results were not definitive enough to make

an unequivocal statement regarding the presence or absence of faulting within Cretaceous materials at RMA. Evidence suggesting the presence of faults include orientation of paleochannels, potentiometric surface anomalies, the presence of a sedimentary dike on Rattlesnake Hill and local reversals in dip or apparent offsets of marker beds. The following conclusions have been reached by contractors working on the site:

- o Alternative explanations exist for those locations where faults are suspected;
- o No conclusive evidence of Quaternary fault movement has been observed in the alluvial deposits;
- o The likelihood of active faults in Holocene or older sediments is remote;
- o No definitive manifestation of faults in the Denver Formation are present on site, however the possibility of a fault(s) cannot be summarily dismissed based upon present data; and
- o Detailed site-specific investigative work associated with remediation efforts are likely to substantiate the presence or absence of faults on the site.

2.2.4.3 Fractures

Historically, fractures have been noted from borehole information but there is limited data on the extent or direction of fracturing. The lignites tend to exhibit more fracturing than the other rock types. Fracture density noted in well logs typically decreases with increasing depth below land surface. Evidence relating fracture occurrence to tectonic activity is not conclusive.

2.2.5 Geologic History

The Denver Basin was downwarped during Late Cretaceous and Early Tertiary time. Fluvial sands and clays of the Arapahoe and Denver Formations were deposited in the basin during this time, unconformably overlying older Cretaceous age sediments. Sedimentation continued throughout the Tertiary Period. Subsequent regional uplift resulted in erosion of more than 1,000 ft of sediment overlying the Denver Formation. With continued erosion, stream channels up to 100 ft deep were incised into the surface of the Denver Formation. Quaternary age surficial material deposited on this erosional surface, consists of unconsolidated alluvial gravel, sand, and clay. The surface is covered by Holocene age eolian deposits.

The Denver Formation exhibits features typical of fluvial floodplain deposits such as fining upward sequences (sandstone to siltstone to claystone) typically capped by thin lignitic intervals. Figure 2.2-15 is a schematic diagram of an active fluvial system illustrating typical associated deposits. Generally, sediments are deposited and reworked with time as the stream migrates laterally across the floodplain. Aggrading streams build up deposits which may be partially, or rarely completely, preserved in the stratigraphic record. Degrading streams down-cut into the underlying sediments or bedrock, causing the formation of terraces or benches, respectively.

Associated deposits include: sandy point-bars with coarser basal channel lag deposits; sandy channel-fills, natural levees, crevasse-splay or overbank deposits; and fine-grained and organic rich floodplain deposits. Point bars form within the stream channel along the inside of a meander curve where energy from flowing water is reduced and deposition is possible. Sandy channel-fills, and sometimes clay plugs, in-fill abandoned channels cut off from the main stream channel. Natural levees, or confining banks, often form along streams. During flooding, however, these levees may be breached resulting in a pulse of sediment-laden water flowing onto the floodplain. The resulting medium- to fine-grained deposits are known as crevasse-splay. They are typically lobate in shape and resemble miniature deltas. Quiet, low-lying areas on the floodplain accumulate organic-rich (lignitic) materials and fine-grained sediments.

A well-preserved point bar sequence usually overlies a claystone or organic-rich (lignitic) layer, representing the uppermost interval of an underlying point bar sequence. The basal point bar is coarse-grained or gravelly channel lag preserved as conglomerate or very coarse-grained sandstone. The channel lag is overlain by sandstone which becomes finer-grained with decreasing depth (fining-upwards). The uppermost very fine-grained sandstone grades vertically into siltstone, claystone and finally lignite. The uppermost lignite forms the base upon which the next point bar sequence is deposited.

Zones 5 through 9 of the Denver Formation are characterized by continental sediments deposited on a piedmont plain (Weimer, 1973, RIC#81266R59). Distribution patterns and lithologic data indicate Zone 4 consists of overbank and crevasse-splay deposits with a facies change to the north where sandstones have been identified (ESE, 1988e, RIC#88344R02). A north-to-south trending sandstone occurs along the western margin of RMA, and may represent an area of channel deposition. Lateral continuity between

sandstones in the north and west portions of the site could not be confirmed with the available data.

Zone 3 sandstone, in excess of 20 ft thick, occurs in Sections 2 and 25, indicating channel deposition. Zone 3 sandstones in Sections 23 and 24 locally contain interbedded claystones and are interpreted to be crevasse-splay or overbank deposits. A northeast-to-southwest trending sandstone occurs in the northwest portion of RMA, possibly indicating an area of point bar deposition.

In Zone A, alternating sequences of crevasse-splay or overbank sandstone, claystone, and siltstone occur as facies which are laterally equivalent to the channel sandstones. These intervals are generally associated with Units AM and AL.

Quaternary alluvium was unconformably deposited on the undulating erosional surface (Plate 7) developed on exposed rocks of the Denver Formation. The surface is characterized by paleochannels formed by pre-Pleistocene erosional events. These paleochannels are illustrated in a block diagram shown on Plate 7. The view is from the northwest to the southeast with a 4:1 vertical exaggeration.

Three prominent paleochannels cross the RMA site and a fourth is located to the northwest (Figure 2.2-16). The three paleochannels, and their tributaries, trend northwest and continue off-post where they join the fourth paleochannel. The First Creek paleochannel is the easternmost and is present at the northern boundary of Section 24. The central paleochannel, commonly referred to as the Basin A Neck paleochannel, originates near Basin A in Section 36 and exits the site in Section 22 near the Northwest Boundary Containment System. The southern paleochannel trends northwest across the southwest part of the site and exits at the western boundary of Section 33. This system may be a paleochannel of Sand Creek. The fourth paleochannel, northwest of the site, trends northeast and may be a South Platte River paleochannel. Numerous less prominent paleochannels occur throughout the site.

Topographic highs commonly mimic the underlying bedrock surface. These features exhibit varying degrees of decomposition, attributable to weathering of the exposed bedrock and/or possible secondary alteration along the alluvium-bedrock contact. Topographic

bedrock highs include Rattlesnake Hill in Section 35, GB Hill in Section 25 and Henderson Hill near the northern RMA boundary in Section 19.

Surficial Quaternary Alluvial and eolian sediments cover most of the RMA site. The generally coarse-grained nature of the older units, Verdos, Slocum, Louviers and Broadway, indicates they were deposited under high energy, post-glacial and interglacial fluvial conditions associated with the distal portions of reworked alluvial fans, fluvial terraces and floodplain deposits. The younger units (Loess/Eolian, Piney Creek and Post Piney Creek) are finer-grained eolian or low-energy stream sediments. Surficial eolian sediments may blanket other alluvial units (Figure 2.2-11).

2.3 Surface Water

The local hydrogeological setting is discussed in two parts: surface water and groundwater. Surface water systems are described first, followed by a discussion of the monitoring programs, results and interpretation. The groundwater system is discussed in Section 2.4.

2.3.1 Local Hydrogeologic Setting

On the RMA, surface water features include perennial streams, irrigation ditches, freshwater lakes and liquid waste disposal basins. The features are described briefly by drainage basin. A water balance for the important surface water features is included after the brief descriptions of drainage basins. The interaction between surface and groundwater is discussed briefly with the water balance and in more detail in Section 2.4.4

There are five drainage basins and three sub-basins that cross the RMA (Figure 2.3-1). From southwest to northeast, the drainages are Sand Creek, Irondale Gulch, Northwest, First Creek and Second Creek. The sub-basins are Basin A and Sand Creek Lateral within the First Creek Basin and Basin F within the Northwest Drainage Basin. Of these, Irondale Gulch, Northwest and First Creek Drainages cover the largest areas and include the most significant surface water features.

The Irondale Gulch Drainage originates southeast of the RMA. This drainage includes seven freshwater lakes (Lake Mary, Ladora Lake, Upper Derby and Lower Derby Lakes,

Havana Pond, Rod and Gun Club Pond, three interceptors (Peoria, Havana and Uvalda), two canal laterals (Sand Creek and Highline) and one storm drainage ditch (South Plants Ditch) (Figures 2.3-2). All of these features are manmade; none directly transmit water outside the boundaries of the RMA.

The four largest lakes are Upper and Lower Derby Lakes, Lake Ladora and Lake Mary. Surface water features in the vicinity of the lakes are shown in Figure 2.3-3 and are described briefly below.

Upper Derby Lake, located in the eastern half of Section 1, receives surface water from the Highline Lateral. The Highline Lateral originates at the Highline Canal 2 1/2 miles southeast of the site and flows northwest. Water from the Lateral can be diverted either to Upper Derby Lake or to Lower Derby Lake via the Highline Lateral.

Lower Derby Lake is located in the southwest quarter of Section 1. It receives water from Montbello via the Uvalda Interceptor, Upper Derby Lake via a sluice gate, South Plants via South Plants Ditch, the Rod and Gun Club Lake via an unnamed ditch and Highline Lateral via a diversion located at the southeast corner of Section 1.

Ladora Lake receives water from Lower Derby Lake and Sand Creek Lateral. Water levels are controlled by a pumphouse located on the northwest side of the lake. Overflows from Ladora Lake flow south of Lake Mary into Section 3, where the water evaporates or infiltrates into the soil.

Lake Mary, located west of Lake Ladora, receives water from a drainage culvert at the northwest end of the lake. Overflows from Lake Mary and Lake Ladora flow north along C Street through a culvert under the roadway and into a small impoundment area to the west. The impoundment does not overflow under normal conditions; however, the embankment was deliberately breached to test overflow pathways.

The First Creek Drainage Basin crosses the RMA immediately north of the Irondale Gulch Basin. The drainage upstream from RMA is largely undeveloped, but increasing urban development and associated impervious surfaces (i.e. pavement and structures) is decreasing infiltration and increasing surface runoff.

First Creek is the dominant surface water feature in the First Creek Drainage. It is an intermittent stream that loses water to infiltration and evaporation across the RMA. Maximum stream flow usually occurs in May when First Creek gains water from precipitation during storms. During active use of the RMA, ditches from the North Plants and the waste water treatment facility in Section 24 also discharged surface water into the North Bog, part of the First Creek Drainage.

North Bog is a 2.7 acre body of water located in a natural depression in the northwest quarter of Section 24. During high flow events water from First Creek flows into the bog. Since 1983, North Bog has been used as a natural recharge basin for treated groundwater from the North Boundary Containment System.

There are two artificial sub-basins located within the First Creek Drainage Basin: Basin A and Sand Creek Lateral (Figure 2.3-1).

Basin A sub-basin consists primarily of the liquid waste disposal basin, Basin A, which was constructed in a natural depression in 1945 to dispose of liquid wastes by evaporation and infiltration. Over w from Basin A flowed north across sub-basin boundaries into Basins B, C, D, E and G located in the Basin F sub-basin. The basins have not been used for waste disposal since 1958, and storm events have not caused water to overflow from one to the next since 1964. (COE, 1983, RIC#84066R01).

Sand Creek lateral sub-basin is bound on the west by the Sand Creek Lateral and on the east by the western border of Basin A. Sand Creek Lateral is one of the only surface water features on the RMA that crosses drainage boundaries.

The Northwest Drainage originates on the RMA on the western edge of the First Creek and Irondale Gulch Basins. It contains no surface water features except for those in the Basin F sub-basin. The Basin F sub-basin is located on the eastern edge of the Northwest Drainage. It is an artificial sub-basin that includes four manmade liquid waste disposal basins referred to as Basins C, D, E and F. Basins C, D and E are unlined and received overflow wastes from Basin A between 1953 and 1956. Basin C was also used to store large volumes of fresh water in 1967, 1968 and 1969-1974. Basin F was an asphalt-lined disposal basin constructed in 1956; it received wastes until 1982 via buried chemical sewer lines.

The Sand Creek Drainage crosses the far western tier of the RMA. It is characterized by poorly developed stream channels and high soil infiltration rates. The Second Creek Drainage crosses the extreme northeastern tip of the RMA. On the RMA, it is characterized by moderate infiltration rates. No surface water features in either the Second Creek or Sand Creek Drainage Basins occur on RMA.

Figure 2.3-1 illustrates different soil infiltration rates associated with each drainage basin. First Creek Basin is predominated by low and high infiltration rates in the upper and mid-reaches, respectively and by moderate rates on the site. Irondale Gulch and Sand Creek Drainage Basins are characterized by high infiltration rates. Northwest and Second Creek drainages are mainly low infiltration areas. The more permeable soils within Irondale Gulch drainage result in poorly defined stream channel development in contrast to the low infiltration areas typifying First and Second Creek basins.

Infiltration and percolation involve the movement of water into the soil surface and through the soil mass. Estimated infiltration capacities are generally based upon Soil Conservation Service (SCS) maps and published values for permeability and hydraulic conductivity. A Resource Consultants, Inc. Report (RCI, 1982, RIC#82096R01), produced a map similar to Figure 2.3-1, where the low, moderate and high infiltration soils were assumed to have infiltration capacities of 0.10, 0.75 and 3.0 inches per hour (in/hr), respectively. The values were based upon SCS data (RCI, 1982, RIC#82096R01).

A later RCI report included results of a double ring infiltrometer study conducted in Basin A and the South Plants area. For Basin A soils, consistent initial infiltration rates were consistently near 0.3 in/hr and declined to 0.01 in/hr in less than 4 hours. A single measurement in an undisturbed, unvegetated area of the South Plants had an initial infiltration rate of approximately 8 in/hr and declined to 2 in/hr in 2 hours (RCI, 1983, RIC#83235R01).

2.3.2 Surface Water Monitoring Systems

Over the years, a number of surface water studies have been performed by individual contractors. In 1982, a contract was awarded to Resource Consultants, Inc. to install ten stream-gaging stations to verify previous water balance studies. Recorders, operated

between the spring of 1982 and September 1983, were installed at First Creek (upstream or south), north and south Uvalda Interceptors, Basin A, Ladora Weir, and South Plants Ditch. A staff gage was installed at Havana Pond, and Shell maintained a gage on Highline Lateral. In the summer of 1983, four additional recorders were installed at Havana and Peoria Interceptors, Havana Pond and North First Creek; however, rating curves were not developed and stream discharge was not determined (RCI, 1984, RIC#85728R04).

Streamflow was monitored from May through December of 1984 under a second contract which also provided for the installation of concrete controls in the natural channels and for an additional recording station at Havana Pond (Dildine, 1984, RIC#85350R01). A report explaining data reduction techniques and the accuracy of the results was never furnished for this study, consequently data resulting from the monitoring efforts were of limited value.

In 1985, the surface water monitoring program became a part of the Task 44 effort under the direction of ESE. The resulting monitoring network eventually included twelve continuous water-level recorders, four staff gages, and two on-post raingages. Data were collected continuously (or estimated to provide a continuous record) from this network from October 1, 1985 through November 30, 1987 and used to calculate water balance components for each drainage basin.

Figure 2.3-2 shows the location of all monitoring stations equipped with Stevens Type F water level recorders. Changes or gage additions to the existing system were relocation of the Ladora Weir gage and the installation of a gage on First Creek (downstream or north) at Highway 2. All stations except Basin A, Highline Lateral, Havana Interceptor and Havana Pond required substantial modification involving repairing, replacing, or installing a control structure and stabilizing natural channel sections using rock-filled gabions. Table 2.3-1 describes the control structures and provides staff gage information at the various gaging locations following restoration.

Table 2.3-1 Control Structures and Gaging Locations

Gaging Stations	Type of Channel Control	Coordinate Location		Gage Ht. Elevation ¹	Minimum Crest Stage	Staff Gage Range	Overflow Stage
		northing	easting				
Peoria Intercept	Sharp Crested Weir	170,266.57	2,179,583.59	5,248.21	1.00	0.00-3.3	NA
Havana Intercept	Concrete Lined Section	170,977.58	2,178,880.70	5,252.14	0.00	0.00-6.6	7.00
Havana Pond	NA	172,675.98	2,180,135.35	5,244.15	-2.50	0.00-10.	9.50
Ladonia Weir	Sharp Crested Weir	176,315.43	2,183,668.16	5,229.85	4.12	3.33-6.6	6.62
South Uvalda	Compound Weir	170,441.11	2,186,764.00	5,271.71	3.47	3.33-6.6	NA
North Uvalda	Triangular Weir	175,606.19	2,187,897.86	5,255.74	-0.07	0.00-3.3	NA
Hughline Lateral	8 ft Cipolletti Weir	-	-	-	0.00	0.00-2.0	2.00
South 1st Creek	Triangular Weir	175,609.41	2,197,123.86	5,278.54	0.36	0.00-3.3	NA
North 1st Creek	Triangular Weir	195,528.94	2,187,041.43	5,139.40	3.50	3.33-6.6	NA
S. Plants Ditch	Sharp Crested Weir	177,784.30	2,185,805.53	5,252.83	3.77	3.33-6.6	6.77
Brown A	V-notch Weir	180,995.06	2,184,525.70	5,252.04	0.00	0.00-3.3	2.00
1st Creek Hwy 2	H Flume	199,060.03	2,180,842.21	5,106.82	0.00	0.00-2.5	<2.50

¹ Elevations given correspond to the 0.00 foot datum relative to the staff gages at the various stream gaging station locations
NA = Not available

Source: USF, 1988

Upper and Lower Derby Lakes, Ladora Lake and Lake Mary, equipped with staff gages, were read on a weekly basis. The staff gages on Upper and Lower Derby Lake and Ladora Lake were installed upon completion of the respective embankments. The staff gage on Lake Mary was installed in September 1985. Table 2.3-2 contains the lake-staff gage descriptions.

The location of two pump-flow meters are included in Figure 2.3-2. A meter in the Ladora Pumpouse monitors water removed from Ladora Lake for steam generation and other industrial uses. The Sewage Treatment Plant meter monitors plant discharges into a tributary of First Creek.

2.3.2.1 Streamflow

Stream stage data were collected with Stevens Type F water level recorders. These analog recorders produce a graphic plot of stream stage continuously with time. The gages operate on an 8-day cycle with an accuracy of 2 hours. Recorder accuracy is 0.05 ft.

The water level recorders are located in plywood instrument shelters resting on top of 24-inch diameter corrugated metal pipe stilling wells. The wells are either instream or connected to the channel via a short perpendicular ditch. The natural stream channels have stilling wells set into the banks with two inlet pipes connecting the wells to the stream channel. Stilling wells installed off-channel are sealed at the base to prevent groundwater intrusion.

An estimate of the water level stage for each hour, to the nearest 0.05 ft, is interpreted from the recorder chart trace, recorded on a data sheet and entered into a computer data file. Hourly stages are converted by a computer program into discharges which are output as monthly discharge volumes in acre-feet/month (ac-ft/mo). Rating curves (plots of discharge measurements for various stages), are computed using a FORTRAN IV program. The rating curves are constructed as outlined in the National Handbook of Recommended Methods for Water-Data Acquisition (USGS, 1977).

Table 2.3-2 RMA Lake Staff Gage Data (in ft)

Lake Staff Gages	Gage Height Elevation at 0.0 Datum	Minimum Lake Stage	Staff Gage Range	Overflow Stage
Upper Derby	5,249.25	-2.35	0.0-10.0	9.0
Lower Derby	5,231.00	-2.40	3.0-21.0	21.2
Lake Ladora	5,208.00	-4.00	0.0-13.0	12.4
Lake Mary	5,202.70	NA	0.0-2.0	1.34

NA - not available

Source: ESE, 1988.

The rating curves for all of the gages are given in Appendix B, which also contains monthly stream discharges from October 1985 through November 1987. Table 2.3-3 contains average, maximum, and minimum stream flows and annual flow volumes for the 1986 and 1987 water years (WY86 and WY87), where a water year is defined by the United States Geological Survey as the period from October 1 to September 30.

The monthly water balance format, provided by the Army, covers three stream channels and four lakes. Table 2.3-4 contains a spreadsheet of the water balance computations. Two components not included in these calculations were transpiration and overland flow. Because these water balance computations were prepared primarily for the lakes, these components were not deemed to be critical to the end results.

Although the data are the best to date, stream flow monitoring was not continuous. The conversion from stream stage to discharge, or lake stage to area or volume, is dependent upon stream rating, stage-volume relationships, and stage-area relationships which are not always predictable. Errors may be associated with instrument error, rating curve development, discharge calculations, data reduction, and recorder downtime. Accuracy of the Stevens Recorders is less significant than errors attributable to the data reduction techniques.

Rating curve errors are attributed to inaccuracies associated with the gaging measurements and curve extrapolation. The stream gaging measurements used to determine the discharges at different stages are considered accurate within 10 percent (USGS, 1977). Infrequent flood occurrences and associated short peaks with large discharges cannot always be verified. The rating curves for higher flows were therefore extrapolated using the HEC-2 computer program outlined by the COE (1982).

Nearly continuous stream discharge records have been generated for the gaging sites; however, there have been periods when the gages were inoperative or the data were considered unreliable. Gages were inoperative each winter due to freezing conditions from December 3, 1985 to March 4, 1986 and from December 8, 1986 to March 30, 1987. During these periods, stream staff gages were read on a weekly basis and hourly data were assumed to be a linear interpolation of the weekly readings. This assumption is acceptable because flow conditions were typically low and constant for these periods.

Table 2.3-3 Characteristic Flow Statistics for Stream Gaging Stations at RMA

Station	Mean Monthly (ac-ft/mo)	Estimated Maximum Instantaneous (cfs)	Estimated Minimum Instantaneous (cfs)	WY86 Total** (ac-ft)	WY87 Total** (ac-ft)
Peoria Intercept	11.7	230	0	92	211
Havana Intercept	98.4	677	0	1088	1276
Ladora Weir	8.4	16	0	76	141
South Uvalda	52.2	202	0.2	621	
North Uvalda	53.1	55	0	688	659
Highline Lateral	29.6	14.4	0	308	462
South First Creek	82.2	380+	0	1006	1003
North First Creek	69.3	213	0	1068	733
South Plants Ditch	0.0	Trace	0	0	0
Basin A	0.8	5.6	0	9.6	10.4
First Creek at Hwy 2	24.7	23.2	0	*	413

ac-ft Acre foot

ac-ft/mo Acre foot per month

cfs Cubic foot per second

* No data available

** WY Water Year defined as October 1 through September 30

Source: ESE, 1988.

Table 2.3-4. Annual Monthly Water Balance Summary
(All Units in Acre Feet.)

2.3.2.2 Lake Levels

Lake level data were collected on a weekly basis. Upper Derby, Lower Derby and Ladora Lake have staff gages installed and maintained by the Army. These gages have an accuracy of 0.1 ft. Stage data are collected several times each day for Lower Derby Lake and Ladora Lake by Stearns Catalytic, an Army-maintenance subcontractor.

Lake Mary and Havana Pond have Stevens Style C staff gages which have an accuracy of 0.01 ft. Havana Pond is also equipped with a Stevens Type F water level recorder. The Stevens recorder is calibrated weekly using the staff gage readings.

Lake balance analysis involves the comparison of observed monthly volume to a calculated volume. Calculated volume is determined by adding stream and precipitation inflow during a month to the initial lake volume measured at the beginning of the month, and subtracting losses from evaporation and lake releases over the same period. If the calculated volume at the end of a month is less than the measured volume, the difference represents water losses that are attributed to infiltration or seepage of surface water into the subsurface. Calculated volumes represent volumes greater than measured volumes represent water gains.

Lake stage data are used to measure lake volumes and areas. The difference in lake volumes for the beginning and end of each month are taken from the appropriate stage-volume table and represent the measured monthly gain or loss for the lake in the water balance. Estimated monthly precipitation and evaporation volumes are obtained by multiplying the mean lake area by total monthly precipitation and evaporation. Mean areas for the lakes are assumed to be equal to the average of the areas at the beginning and end of the month, as determined by the stage-area tables. Stage-area and stage-volume relationships for each lake have been included in tabular form in Appendix B.

Stage-volume curves originally created by Shell for Ladora, Upper Derby and Lower Derby Lakes were obtained from Stearns Catalytic. When the stage-area relationships were calculated from the stage-volume curves, errors were detected. Estimates of more realistic curves were developed as outlined in the report Review and Proposed Revision of Stage-Volume Curves for RMA's Lower Lakes (RCI, 1986). The original stage-area curves for the lakes (Whitman et al., 1943) were used to develop the stage-area and stage-volume

tables in Appendix B. Although sedimentation and sediment removal have occurred in the lakes and have affected area and volume calculations, these data are still considered the best available. Since three different stage-volume relationships exist for the lakes, data may not be comparable to other sources. Lake volume data are presented in Table 2.3-4, with more complete data presented in Appendix B.

2.3.2.3 Precipitation and Evaporation

The precipitation monitoring network consists of one off-post station operated by the National Weather Service at Stapleton International Airport (approximately 2 miles south of RMA) and two on-post stations operated by ESE (Figure 2.3-2). Data generated by the National Weather Service station are obtained through the Colorado Climate Center (CCC) in Fort Collins, Colorado. The two on-post stations are each equipped with a WEATHERTRONICS Model 6010 tipping bucket raingage. These gages have 9 inch collectors and are heated using a low wattage light bulb for measurement of snow water equivalences. Precipitation entering the raingage collector is funneled into a 0.01 inch bucket which tips upon filling. This triggers the advancement of a pen one notch on a remotely located Model 6113 Event Recorder Chart. The event recorder records 100 events from the bottom to the top of the chart then returns to zero for continuous recycling. The gage is accurate to within one hour and the precipitation depth has an accuracy of 0.01 inch. Heating the gages during the winter months and exposure to desiccating winds may affect the data quality.

Raingage charts were reduced as described by the Field Manual for Research in Agricultural Hydrology (Brakensiek et al., 1979). Daily precipitation data were extracted from the on-post gage charts and averaged with the Stapleton International Airport data to obtain the precipitation depth in inches. Data considered unrepresentative were omitted from the calculations. Precipitation data are included in Appendix B.

Pan evaporation data collected at Cherry Creek Reservoir, located 12 miles south of the site, are the best available for the area and were accepted as representative of RMA lake evaporation. The Cherry Creek data are collected by means of a Class A pan and were obtained from the COE (1987). The Corps of Engineers use a coefficient of 0.70 for Class A pan data to relate monthly pan evaporation with monthly lake evaporation. Pan and lake evaporation data are included in Appendix B.

Monthly precipitation, evaporation, and net evaporation data for the monitoring period are summarized in Figure 2.3-4. Monthly precipitation shows seasonal variation with the greatest precipitation, recorded at Stapleton International Airport, during May (2.46 inch/mo) and least in January (0.52 inch/mo). Evaporation values maintain a fairly uniform seasonal cycle with the greatest losses in July (6 inch/mo) and the least in January (0.50 inch/mo). Net evaporation data, calculated by adding the precipitation to the evaporation losses, represent the net loss from a free-water surface. Because the precipitation is usually exceeded by evaporation, the net evaporation values almost always represent a loss of free-water surfaces at the site.

2.3.2.4 Utilities

Flow meter readings for both the Sewage Treatment Plant and the Ladora Pumphouse gages were collected on a weekly basis and on the first of the month. Stearns Catalytic maintains a continuous record for the Ladora Pumphouse gage. Recorder charts were changed weekly for the gages and for the digital-accumulators, which digitally accumulate flow data. Monthly water volumes, in gallons, are obtained by subtracting readings taken at the first of the month from those taken at the end of the month. The resulting flow volumes are converted to acre-feet. Meter and lake data are shown in Table 2.3-4 in ac-ft/mo. The average flows at the Ladora Pumphouse and the Sewage Treatment Plant are 3.4 and 1.0 ac-ft, respectively.

2.3.3 Water Balance Results

The surface water system receives water from precipitation and loses water through evaporation. Water is also received and lost naturally through interaction with the groundwater system. Water is artificially supplied to or removed from the system through a series of manmade structures. The following discussion describes conditions during the monitoring period and discusses water balances for First Creek Drainage, Irondale Drainage, Basins A and F Drainages, and Sand Creek Lateral and Northwest Drainages. Water balance results are summarized in Table 2.3-3. A monthly format was specified for the water-balance analyses.

2.3.3.1 First Creek Drainage

Baseflow, or that part of stream discharge derived from groundwater seeping into the stream, is absent over intermittent stream segments through much of the year. Baseflow, estimated by monthly minimum discharge, is highest during February and March with flows of 1 cfs or greater. Average monthly mean discharge for First Creek is 82 cfs for the south gage upstream and 57 cfs for the north gage, downstream. The diminished flow volume downstream, contrary to normally increasing flow in this direction, reflects groundwater recharge along the stream.

2.3.3.2 Irondale Drainage

The stage data for Upper Derby Lake demonstrates that the lake contained approximately 35 ac-ft of water at the beginning of the monitoring period. The water level steadily declined to the point of dryness by June 1986. The only significant inflow during the monitoring period resulted from a large storm in July 1987 which caused the Uvalda Interceptor to overflow into Upper Derby Lake.

For WY86 and WY87, stage data for Lower Derby Lake indicate that the lake levels steadily declined from October through April. For both water years, the level of Lower Derby Lake dropped 1.6 ft. During the period from May through September, erratic water level fluctuations were observed, resulting from short-duration, high-intensity thunderstorm inflows. The long term trend indicated that the level of Lower Derby Lake steadily declined over the study period. October 1 stages for 1985, 1986, and 1987 were 16.9, 15.8, and 15.3, respectively.

Ladora Lake monthly stages ranged from 11.5 ft to 12.5 ft. The stages did not fluctuate as much as the Lower Derby stages because Ladora Lake is maintained at a level near the overflow state of 12.35 ft and the primary inflow through Ladora Weir is regulated to maintain a fairly constant lake level. An annual cycle of lake stages was evident with the maximum stage occurring in March at around 12.4 ft and the minimum occurring between September and October at a stage of 11.6 ft.

Lake Mary stages are quite constant. The WY86 average stage was 1.22 ft, with a standard deviation of 0.41 ft. The WY87 average stage was 0.70 ft with a standard

deviation of 0.33 ft. The minimum monthly stage of 0.09 ft was recorded on October 1, 1987 and the maximum, 1.61 ft, on February 1, 1986.

Havana Pond monthly stages have recorded fluctuations of over 4 ft. A maximum stage of 4.33 ft was recorded on July 1, 1987. From January 1 through April 1, 1986 the pond level remained constant. The seasonal trend for Havana Pond monthly stages indicated that the lowest levels occur around January, and the highest levels occur during the summer.

During the 2-year monitoring period, water from the Highline Canal was diverted into the Highline Lateral five times between June and September. This water was channeled into Lower Derby Lake, by-passing Upper Derby Lake. The canal was artificially controlled and the flows were fairly constant, averaging 10.7 cfs with a standard deviation of 1.6 cfs.

The water balance summary (Table 2.3-4) shows that Uvalda Interceptor is perennial. Peak flow at the South Uvalda gage has exceeded 200 cfs, although flows as low as 0.4 have been recorded. Large flows may be partially diverted at a culvert a short distance upstream of the North Uvalda gage. Flow exceeding the culvert capacity is diverted into Upper Derby Lake.

The sluice gate controlling outflow from Upper Derby Lake into Lower Derby Lake was closed during the monitoring period. Inflow from the South Plants Ditch were negligible, typically related to precipitation events. Water balance calculations indicate that these lakes have unaccountable water losses for 25 of the 26 month-long monitoring program, suggesting that lake levels are above the water table and resulting in a net loss to groundwater.

Water was released from Havana Pond into Sand Creek Lateral twice during the monitoring period. Water released from the pond may have been lost to canal seepage prior to reaching Ladora Lake.

Discharge from Lower Derby Lake into Ladora Lake is controlled manually and generally results in peak flows of 6 to 16 cfs. Discharge usually occurs between July and October when net evaporation is greatest and lake levels are lowest. Ladora Lake also may

receive inflow from Sand Creek Lateral. The lake also receives inflow from the groundwater system. Ladora Lake loses water by seepage, pumping via the Ladora Pump house, or overflow. Overflows occurred during the monitoring period between December and May. Overflows were not gaged continuously but one peak flow measurement was 14.3 cfs, corresponding to 12.85 ft on the Ladora Lake staff gage. Typically, overflows average 1 cfs. Overflowing water travels south of Lake Mary into Section 3 where it is lost to evapotranspiration and infiltration.

Groundwater is the primary source of water to Lake Mary. Lake Mary rarely receives inflow from a drainage culvert on the northeast lake edge. Evaporation generally exceeds precipitation (Figure 2.3-4). Seepage from Ladora Lake into the east side of Lake Mary is the most likely groundwater source (Figure 2.3-5).

The Havana Interceptor contributes 10 percent of the flow in the Irondale Gulch Basin. The interceptor flows over a relatively impervious surface drawing water from a small watershed; therefore inflow into Havana Pond reflects precipitation events.

Havana Pond released water to Sand Creek Lateral twice during the monitoring period. Havana Pond, with a maximum capacity of approximately 285 ac-ft, is located above the water table in sandy soils. The resulting net loss to groundwater and evaporation is large, 17 ac-ft per day for stages greater than 5 ft. Averaged over the 25-month monitoring period, 111 ac-ft/mo of water enters the pond and 3.7 ac-ft/mo are lost to evaporation and 108.3 ac-ft/mo are lost to groundwater.

2.3.3.3 Basins A and F Drainage

Basin A Drainage receives inflow from a storm sewer outlet originating in the South Plants area and two storm drainage culverts underlying Seventh Avenue. Discharge from the South Plants storm sewer outlet is monitored by the Basin A gage. This gage record shows continuous flow suggesting groundwater inflow. Peak flows correspond to precipitation events where runoff from Seventh Avenue storm drainage culverts collects in the basin. Flows are low, varying from 0.1 to 4.3 ac-ft/mo over the monitoring period. Under normal conditions, Basin A Drainage is internal with no outflowing surface water. Water losses are by evaporation and to a lesser degree, by infiltration.

Basin F drainage is internal with inflow limited to precipitation and outflow controlled by evaporation and possible leaking through the asphalt lining.

2.3.3.4 Sand Creek Lateral and Northwest Drainages

Water collecting in the Sand Creek Lateral Drainage has been artificially channeled into the Northwest Drainage. The Northwest Drainage is characterized by low slopes, poorly developed stream channels and drainage structures. For these reasons, very little surface water leaves the site via these drainages.

2.4 Groundwater

2.4.1 Introduction

2.4.1.1 Previous Investigations

Hydrogeologic investigations conducted prior to this study have examined both the local and regional groundwater flow at RMA. Study results have been reported by various authors including Smith et al. (1963, RIC#84324R02), Romero (1976, RIC#81266R69), Stollar and van der Leeden (1981, RIC#81293R05), Robson and Romero (1981, RIC#82350M02), May (1982, RIC#82295R01) and May et al. (1980, RIC#81266R48; 1983, RIC#83299R01).

Hydrogeologic properties including hydraulic conductivity and specific yield or storage coefficient were determined by pumping and slug tests (Zebell et al., 1979, RIC#81266R19; Mitchell, 1976, RIC#81281R04; Vispi, 1978, RIC#81266R70; Black and Veatch, 1980, RIC#81266R25; Bopp et al., 1979; Broughton et al., 1979, RIC#81266R27; HRS, 1986; ESE, 1988e, RIC#88344R02; and ESE, 1988, RIC#89024R02).

Water-level fluctuations between 1956 and 1981 have been assessed by previous investigators (Konikow, 1975, RIC#84324M01; Little, 1979, RIC#81295R16; Stollar and van der Leeden, 1981, RIC#81293R05; and May, 1982, RIC#82295R01). Declining water-level trends were identified by May (1982, RIC#82295R01) in several on-post areas between 1978 and 1981. Declining levels up to 7 ft have been documented in Sections 23 and 24 south of the North Boundary Containment System. Declining water-table elevations of 1.1 to 2.4 ft were also reported in the Basin A area during the same period. Water-level

declines are thought to be due to decreased infiltration in upgradient on-post recharge areas since the 1970's. A comparison of water-table elevation maps prepared by Konikow (1975, RIC#84324M01) and Robson and Romero (1981, RIC#82350M02) show an average decline of approximately 2 ft in the areas downgradient from the North and Northwest Boundary containment systems. These declines may result from variations in recharge conditions and/or increased withdrawal from domestic and commercial and/or industrial pumping.

Water-level elevation and hydrograph data were analyzed for the 6-year period from 1981 to 1987. During this period, the water table elevation generally increased in portions of the central and northwestern RMA and decreased in areas near the boundary containment systems, South Plants and Basin F. These fluctuations are attributed to man's activities in these areas. Although water level fluctuations are observed, the magnitude of change over the 6 year period seldom exceeded 2 ft. The change in extent of the unsaturated alluvium that is caused by these fluctuations varies according to the slopes of the alluvium-bedrock contact. The slopes of most bedrock highs that bound unsaturated areas are sufficiently steep to prevent substantial changes in the extent of unsaturated alluvium during the 6 years of investigation. The water-table configuration observed during 1987 study appears to be essentially the same as that observed during 1981, with some local exceptions.

2.4.1.2 General Features

Groundwater in the Denver Basin occurs in surficial Quaternary deposits and in water-bearing zones within underlying formations. The formations comprising the four major bedrock aquifers within the Denver Basin are, from oldest to youngest, the Laramie/Fox Hills Formations of Late Cretaceous age, the Arapahoe Formation of Late Cretaceous Age, the Denver Formation of Late Cretaceous to Early Tertiary age and the Dawson Arkose of Tertiary age (not present at the site) (Figure 2.2-2; Romero, 1976, RIC#81266R69). The Late Cretaceous Pierre Shale underlies the Fox Hills Sandstone and is considered the base of the bedrock-aquifer system due to its great thickness (8,000 ft) and relatively impermeable nature (Robson and Romero, 1981, RIC#82350M02).

Geologic units of primary concern within the study area are the Quaternary age alluvium/eolian surficial deposits and the underlying Denver Formation. Water-bearing

zones within these units comprise the shallow groundwater regime beneath the study area. Deeper aquifers, such as the Arapahoe and Laramie/Fox Hills, at depths of 200 ft or greater, are separated from the Denver Formation by 20 to 50 ft of clayshale and clay (Buffer Zone) acting as an aquitard. The Denver Formation is divided between the Denver aquifer and the Unconfined Flow System on the basis of local geological variations. Surficial material at RMA is water-bearing in most locations and is part of the Unconfined Flow System.

2.4.1.3 Objectives and Methods

Evaluation of the hydrogeologic setting at RMA is based on the integration and interpretation of data collected previously and/or during this phase of the Water Remedial Investigation. The objective of this investigation is to provide a comprehensive understanding of the hydrogeologic framework necessary to assess groundwater flow and contaminant transport and to develop future remedial measures.

A database, used to assess the hydrogeologic setting, was compiled from data reports obtained from the Army, Shell, U. S. EPA, Colorado Department of Health, Colorado State Engineer's Office, South Adams County Water and Sanitation District and Stapleton International Airport. The database includes geologic descriptions from drilling logs, borehole geophysical data, well construction information, water-level measurements, water-quantity data, aquifer test data, and the results of earlier hydrogeologic interpretations. Additional hydrogeologic information was collected during this study by installing and testing wells, measuring water levels, and preparing detailed geologic cross-section and maps. Hydrogeologic data generated by Tasks 1, 19, 21, 25, 26, 36, 38, 39, and 44) also were incorporated.

Pumping tests with observation wells were performed at 19 sites. Production well tests without observation wells were completed at 11 sites. For each pumping test, data and analyses presented in the original report were reviewed in detail. Questionable test data were re-analyzed when reported hydraulic conductivity ranges were too variable to be of value in site characterization (ESE, 1988e, RIC#88344R02). After reviewing these original data and the results of the second analysis, average hydraulic conductivity values were estimated for each test. These values are presented in Appendix B.

Water-level measurements from approximately 720 wells were used to construct maps. For the time-averaged map, 567 values were mean elevations from 1981 to 1987, 118 were single-event measurements taken in 1986 and 1987, and 26 were measurements taken before 1981. Most of the wells used to construct these maps were screened in the alluvium or in both the alluvium and upper Denver Formation.

In areas of unsaturated alluvium, water-level measurements were used in wells which were completely screened in shallow Denver Formation. Because data are more limited than in areas of saturated alluvium, elevation contours drawn in areas of unsaturated alluvium represent an approximate position of the regional water table. Contours were drawn to show refraction at the saturated alluvium-bedrock contacts, consistent with flow across boundaries between materials with contrasting permeabilities.

To understand present regional water-table conditions, maps were prepared to assess the lateral extent of the Unconfined Flow System. A water-table elevation map was constructed for Third Quarter FY87 (Figure 2.4-1, Plate 11). In addition, a time-averaged water-table map for the period 1981 to 1987 was constructed to characterize the regional water-table configuration across the study area and to take advantage of a larger database for water-level measurements than may be available at any particular time interval (Figure 2.4-2, Plate 12). These maps include the most comprehensive data collected for this project.

The information presented in these and other studies has provided input into the interpretations developed in this report. All investigations have been driven to a lesser or greater extent by known or suspected locations of contaminants. For this reason, data tend to be more extensive in some areas. However, this approach is commensurate with the standard practice of defining the nature and extent of contaminants.

2.4.2 Denver Aquifer

2.4.2.1 Geologic Characteristics

Regionally, the Denver aquifer consists of a 600 to 1,000 ft thick series of interbedded sandstone, siltstone, claystone, clayshale, and lignitic intervals deposited under a fluvial depositional environment. The formation is characterized by abundant shale and claystone

(Robson and Romero, 1981, RIC#82350M02). The fine-grained strata are interbedded with poorly lithified, more permeable sandstone lenses. The sandstones are locally unconsolidated. Where present, calcium carbonate, silica or other cements may decrease the hydraulic conductivity by orders of magnitude (Ertec, 1981, RIC#81352R135).

2.4.2.2 Hydraulic Characteristics

At RMA the water-bearing sandstones are usually confined. The potentiometric surfaces of these confined sandstones generally lie below the water table. The claystones act as confining layers and inhibit vertical flow between the sandstone lenses. At or near the bedrock surface, the claystone is fractured and weathered, and hydraulic communication between the Denver aquifer and Unconfined Flow System is enhanced. The sandstone lenses of the Denver aquifer generally have a potentiometric surface 1 to 2 ft or more below the Unconfined Flow System water-table surface. In areas where sandstones subcrop into alluvium, the water levels of the subcropping units are similar to the water table.

Potentiometric maps were constructed for Denver Formation Zones 4 through A using water-level data from wells that are screened in sandstones within each zone. A review of these potentiometric surface maps provides an indication of potential for groundwater movement both laterally and vertically.

Hydraulic conductivity and storativity were estimated from a large number of pumping and slug tests in wells throughout the central nine sections of RMA. Figure 2.4-3 shows the location of wells tested in the Denver aquifer. Slug tests provide information on flow system properties in the immediate vicinity of a borehole or well. Consequently, effects of well construction can influence slug test results. However, when a large number of such tests are conducted in an area, the data may be evaluated using statistical methods to determine the bulk properties of the system.

A wide range of hydraulic conductivity values resulted from the different wells tested. The heterogeneous and anisotropic nature of the sandstone is partially responsible for the varying results. With the slug test, the portion of the system tested for hydraulic conductivity is smaller than for a pumping test. Most of the head loss occurs within a relatively small distance from the well and the resulting hydraulic conductivity primarily

reflects conditions near the well. This fact may also have an impact on the wide range of observed hydraulic conductivity values.

Data from five pumping tests, two located in the North Boundary Containment System area (Black and Veatch, 1980, RIC#81266R25), one in the Basin A Neck area (May et al., 1983, RIC#83299R01) and two in the South Plants area (Shepherd, 1982), were available for evaluation. Tests in the South Plants area were located in fractured claystone that is considered to be part of the Unconfined Flow System. All pumping tests were conducted for periods of 24 hours to over 200 hours, and water levels were simultaneously measured in observation wells. Table 2.4-1 summarizes the results of the pumping tests.

Hydraulic conductivity results from the slug tests are presented graphically as the histogram shown in Figure 2.4-4. The histogram indicates that the log of hydraulic conductivity has an approximate normal distribution curve which is typical for point measurements for conductivity in geologic media. For such distributions of hydraulic conductivity data, the geometric mean of the population is generally considered the best method for identifying a characteristic value. The geometric mean of available sandstone hydraulic conductivity is 0.37 ft/day (1.3×10^{-4} cm/sec). The standard deviation of the logs for the sample population is approximately one order of magnitude. Values of hydraulic conductivity greater than 2.8×10^{-1} ft/day (1×10^{-4} cm/sec) are generally representative of sandstones, whereas values less than 2.8×10^{-1} ft/day (1×10^{-4} cm/sec) are typical of silt and silty sandstones.

The range of hydraulic conductivity values for Denver Formation sandstones is presented in Table 2.4-2. This table also presents the lithology for the screened interval. Hydraulic conductivity values were derived from slug tests unless otherwise indicated. These values ranged from 4.0×10^{-3} ft/day (1.4×10^{-6} cm/sec) in Zone 4 to 34.0 ft/day (1.2×10^{-2} cm/sec) in Zone 2. The low value in Zone 4 most likely is a result of the high cementation of sandstone. The high value in Zone 2 may be attributed to its uncemented and weathered sandstones.

A limited number of aquifer tests have been conducted in test intervals consisting of claystone. Results of these tests indicate that hydraulic conductivity of claystone is related to the degree of fracturing. Aquifer tests conducted where the claystone is highly

Table 2.4-1 Summary of Results for Pumping Tests in the Denver Formation

Well No. Reference	Bore No.	Denver Fm Zone	Transmissivity		Hydraulic Conductivity		Storativity	Ref- erence
			(ft ² /day)	(cm ² /sec)	(ft/day)	(cm/sec)		
23176	1018	2*	26.7	0.29	1.6	1.2x10 ⁻⁴	0.0036	Black & Veatch, 1980
24154	1042	3*	26.7	0.29	1.1	3.9x10 ⁻⁴	0.001	Black & Veatch, 1980
***	APT-0	As*	13.4-307.5	0.14-3.3	7.7	2.7x10 ⁻³	0.065	May et al., 1983
***	PW-2	A**	190	2.04	3.6	1.27x10 ⁻³	0.006	Shepherd, 1982
***	PW-3	A**	115	1.24	3.4	1.2x10 ⁻³	0.014	Shepherd, 1982

ft²/day Feet squared per day
 cm²/sec Centimeter squared per second
 * Well screened in sandstone
 ** Well screened in fractured claystone
 *** RMA well numbers were not assigned to these sites

Shepherd, W.D., 1982. Letter to Commander of Rocky Mountain Arsenal from J.H. Knaus, Shell Chemical Co., including data from aquifer tests dated May 5, 1982.

Source: ESE, 1988.

Table 2.4-2 Summary of Hydraulic Conductivity (K) of Denver Fm Zones

Well Zone No.	Test Type	High K (ft/day)	Low K (ft/day)	Average K (ft/day)	Lithology of Screened Interval
A 01015* 36072*	Slug Slug	22.7	0.08	6.85	Sandstone Silty sandstone
1u 26064* 36059*	Slug Slug	5.7	0.09	1.72	Coarse grained sandstone Silty sand with clay- stone
1 26140** 35017*	Slug Slug	20.1	0.04	12.9	Medium-coarse grained sandstone Silty sandstone
2 24135+ 23227++	Slug Slug	34.0	0.01	24.8	Fine to medium grained sandstone Silty sandstone
3 26090** 26142**	Slug Slug	6.0	0.03	2.2	Loosely cemented sandstone Clayey-sandstone
4 37372++ 26135+	Slug Slug	0.4	0.004	0.1	Medium-grained sand- stone Siltstone
5 NO DATA					
6 26137+	Slug	--	--	0.01	Siltstone and sandstone
7-9 NO DATA					

- * Well data from Broughton *et al.*, 1979, RIC#81266R27
 ** Well data from Bopp *et al.*, (WES) 1979
 + Well data from May *et al.*, (WES) 1980, RIC#81266R48
 ++ Well data from ESE, 1988

Source: ESE, 1988.

fractured (Table 2.4-1 and Appendix B) have resulted in hydraulic-conductivity estimates between 3 and 4 ft/day. Where fracturing is absent, aquifer tests have not been practical. However, laboratory analysis of cores has resulted in hydraulic conductivity estimates as low as 10^{-9} ft/d (Chen and Associates, 1987, written communication).

Storage coefficient estimates obtained from pumping tests conducted by Shepherd (1982) in the South Plants area ranged from 0.006 to 0.014 (Table 2.4-1). A storage coefficient of 0.065 resulted from a pumping test conducted in the Basin A Neck area by May et al., (1983, RIC#83299R01). This test was conducted in a sandstone with only 5 ft of claystone between the overlying alluvium and the top of the sandstone. Storage coefficient results from pumping tests conducted in the north boundary area ranged from 0.0036 to 0.0001 for Wells 23176 and 23154, respectively. These values are typical for semiconfined to confined flow systems.

2.4.2.3 Recharge

Recharge to the Denver aquifer occurs from natural and man-made sources. Examples of Naturally occurring recharge occurs primarily by vertical leakage from the overlying Unconfined Flow System. Recharge is possible in areas where heads in the Denver aquifer are less than heads in the Unconfined Flow System (Figure 2.4-5).

Although surface water features at RMA are not in direct contact with the Denver Formation, recharge from surface impoundments may occur where sandstone beds or fractured claystones and lignites subcrop and the water table in the alluvium forms a mound beneath the impoundment. This may create a large downward, vertical gradient.

Recharge also occurs as a direct result of man's activities. These include poor well construction, improper abandonment of wells, and excavation work intercepting the Denver aquifer.

Poorly constructed, improperly sealed and/or unknown wells could be acting as conduits for the movement of shallow groundwater into the Denver aquifer. Prior to Federal development of the RMA in 1942, the land was used for agricultural activities such as farming and stock raising. Water for domestic, stock and irrigation purposes was obtained from wells. Measures are being taken to inventory and properly abandon these

wells. The large network of wells installed into the Denver aquifer over the last decade could also be considered potential sources of recharge to the system.

Hydrographs (1981-1987) were examined to assess seasonally dependent water-level variations in the Denver aquifer. The hydrographs were sorted by zones in which the wells were completed and were then visually compared. No consistent, discernible, seasonal patterns were detected in the hydrographs constructed from quarterly data. However, strong seasonal variation have been observed in the vicinity of South Plants and other areas when monthly data are available. Hydrographs are presented in the Rocky Mountain Arsenal Hydrographs (ESE, 1987b, RIC#88015R01) and on Plates 1 and 2 for cross-sections A-A' and C-C'.

2.4.2.4 Denver Aquifer Movement

The potentiometric surface map for Zone 4 indicates that groundwater flow is to the north in Sections 23 and 24 and exhibits an average gradient of approximately 0.008 ft/ft (Figure 2.4-6). Groundwater flow direction depicts a more westerly component in northwestern portions of RMA and a maximum gradient of 0.016 ft/ft occurs in Section 27. Geologic data indicate that fairly thin sheet-like sandstones occur in the Denver Formation south of the North Boundary Containment System (Figure 2.2-5). The configuration of the potentiometric surface indicates a fairly homogeneous lithology in this area.

Groundwater flow in Zone 3 is to the north-northwest in Section 24 with an average gradient of 0.008 ft/ft (Figure 2.4-7). Groundwater flow direction depicts a more westerly component in Section 27, and exhibits a gradient of 0.02 ft/ft in this area. The configuration of the potentiometric surface does not indicate a major change in lithology. A relatively homogeneous sandstone is present in southern portions of Sections 23 and 24. Lithologic variation from a permeable to a less-permeable interval may produce tightened contours on potentiometric maps, and appears to be the cause of the higher gradients in Section 27.

Potentiometric data indicate that groundwater flow in sandstones of Zone 2 is generally to the north near the north boundary of RMA at an average gradient of 0.009 ft/ft (Figure 2.4-8). The potentiometric surface appears to flatten through Sections 23, 24,

and 26; however, this may be more a function of data availability than hydrogeologic conditions. Groundwater flow shows a strong westerly component in the central and western portions of RMA in Zone 2 and exhibits gradients of up to 0.013 ft/ft. Geologic information indicates that Zone 2 contains less sandstone in western portions of Section 27, and this may be the cause for higher gradients observed in this area.

The potentiometric surface of Zone 1 slopes to the north-northwest with an average gradient of 0.006 ft/ft in northern areas of RMA (Figure 2.4-9). The potentiometric surface indicates a more northwesterly flow direction in Sections 26 and 35 and exhibits gradients as high as 0.0101 ft/ft. The gradient in Section 36 is as high as 0.016 ft/ft, with groundwater flow in Zone 1 to the northwest and north. The steep gradient along the eastern margin of Section 25 corresponds to a claystone that occurs within Zone 1 at this location. Similar gradients in the southeast portions of Section 25 also correspond to a low permeability claystone in this area. The configuration of the potentiometric surface in Section 36 indicates that sandstones in this area may exhibit relatively lower permeability than other sandstones in Zone 1.

Groundwater flow in Zone 1U is to the north-northeast in Sections 25 and 36, with an average gradient of 0.009 ft/ft (Figure 2.4-10). The flow direction becomes northwest-to-westerly in Sections 1 and 35, and the gradient varies from 0.016 to 0.0001 ft/ft. A flattened potentiometric surface in portions of Section 2 and western portions of Section 1 reflect the more permeable channel sandstone that is shown in Figure 2.2-9. Changes in the potentiometric surface elsewhere in the study area do not necessarily correspond to mapped sandstone occurrences.

The potentiometric surface for Zone A indicates that the groundwater flow direction varies from northeast and north in Section 36 to west in Sections 2 and 35 (Figure 2.4-11). Gradients vary from approximately 0.03 ft/ft in the northeast portion of Section 36 to 0.004 ft/ft in southern portion of Section 2. The gradient is approximately 0.013 ft/ft in Section 30. The steep gradients in the northeast portion of Section 36 are typical of the low permeability claystone and volcanoclastic rocks within the zone (Figure 2.2-13).

The sandstones within the Denver aquifer are generally hydrologically and geologically distinct; however, the units exhibit hydrologic interaction in some locations on site. Several parameters were assessed to determine the potential for hydraulic interaction.

These included nature and thickness of the confining layer between sandstone zones and differential head and gradient measurements between zones. The direction of the vertical hydraulic gradients between zones at well cluster sites is shown in Figure 2.4-12. The gradients are predominantly downward and vary from 0.05 to 0.3 ft/ft.

The nature of the confining layer between zones was assessed in areas where water levels at well-cluster sites were similar. Zones were considered potentially interconnected if the confining layer was highly fractured, excessively fissile or crumbly, or deeply weathered. Zones were not interconnected where confining layers were hard, dense, or massive, with no indication of fracturing or weathering. These data were used in conjunction with water-level and geologic information to produce the assessment shown in Figure 2.4-13 and Table 2.4-3.

2.4.2.5 Discharge

Regionally, the Denver aquifer discharges to pumping wells and area streams. Discharge also may occur to the overlying Unconfined Flow System where sandstones subcrop. In localized areas of RMA, discharge from the Denver aquifer into the Unconfined Flow System probably occurs where sandstones and fractured lignites and claystones are in direct contact with alluvium.

2.4.3 Unconfined Flow System

2.4.3.1 Geologic Characteristics

Surficial deposits form a relatively continuous mantle over the Denver Formation and are composed of unconsolidated clay and silt deposits containing fine-grained sands which grade downward to coarser sands and sandy gravels. About 55 to 60 percent of the saturated, unconsolidated sediments are sand and gravel, and 40 to 45 percent are silt and clay.

These deposits are generally less than 50 ft thick except where they fill paleochannels. Alluvium in paleochannels is up to 130 ft thick and thins laterally where the bedrock surface is at higher elevations. Vertically, the Unconfined Flow System is defined as the

Table 2.4-3 Areas of Potential Hydrologic Interaction Between Sandstones in the Denver Fm

Interacting Zones	Physical Setting*	Areas Involved
As, Am, Au with upper Al	PI, W	o Southern and Central RMA
Al with lu	F, W	o Southern and Central RMA
A, lu, 1, 2, and 3	PI and/or F	o Basin A Neck o Southern Boundary, Section 35
1 and 2	PI, W, F (limited areas)	o Northern Half, Section 25 o Southern Portion, Section 24 o North Central Portion, Section 26 o South Central Portion, Section 23
2 and 3	PI and/or F	o Isolated Occurrences, Sections 23, 24, 26 o Off-post (no fracturing indicated)
3 and 4	W	o Western Portion of RMA o Northern Boundary of Section 23 o North Central Section 24

- * PI Physical Interconnection
F Fracturing in Intervening Layer
W Equivalent Water Level

Source: ESE, 1988.

saturated portion of these deposits where the upper boundary corresponds to the water table, and the lower boundary is defined by the alluvium/bedrock contact. The saturated thickness of alluvial material is shown in Plate 13. The Unconfined Flow System includes the weathered upper Denver Formation where it behaves as an unconfined system. The Unconfined Flow System is laterally continuous across RMA.

The following criteria were used in delineating the base of the Unconfined Flow System:

- o Where no Denver Formation sandstones subcrop below saturated alluvium, the base is considered to be at the bedrock/alluvium interface;
- o In areas where alluvium is saturated and Denver Formation sandstones subcrop, the base of the subcropping sandstone was considered the base;
- o Within areas of unsaturated alluvium, available geologic logs and water levels from wells were reviewed. The base is considered to be the base of the weathered zone in the Denver Formation;
- o In areas of unsaturated alluvium with little or no well data, the base was determined by extrapolating base elevations from adjacent areas; and
- o In the eastern tier area where minimal contamination was reported, fewer wells were installed and geologic data were sparse; therefore a minimum saturated thickness across areas of unsaturated alluvium was assumed.

A map showing the base of the Unconfined Flow System is presented in Figure 2.4-14 and Plate 14. This map was constructed using geologic data obtained from boring logs, regional cross-sections, and interpretations completed as a part of the geologic investigation.

A saturated thickness map for the Unconfined Flow System (Figure 2.4-15, Plate 15) was produced to illustrate the vertical extent of the system. This map was produced by overlaying the Third Quarter FY87 water-table map on the base of the Unconfined Flow System elevation contour map and determining the saturated thickness at contour intersections. The saturated thickness varies from less than 10 ft to approximately 70 ft and is thickest in the paleochannels. Because the Unconfined Flow System is interpreted to be a laterally continuous flow system, no areas of zero saturated thickness are shown in Figure 2.4-15. However, there are large areas where the saturated thickness is less than seven ft (Sections 20, 26, and 29).

The saturated thickness of alluvium varies from approximately 0 to 70 ft over the study area. The Third Quarter FY87 saturated thickness of alluvium, at a scale of 1 inch equals 5,000 ft, is mapped in Figure 2.4-16. This same information is provided on a map at a scale of 1 inch equals 2,000 ft in Plate 13. These maps were constructed using water level data obtained in the Third Quarter FY87 combined with bedrock elevation data from Figure 2.2-16.

The greatest thickness of saturated alluvium in the on-post area, approximately 70 ft, occurs in the Irondale Gulch paleochannel near the Irondale Containment and Treatment System (Section 33) and near Ladora Lake (Sections 2 and 11). An average thickness of 45 to 50 ft occurs along this paleochannel from the southeast corner of RMA to the South Plate River.

The major paleochannels that trend southeast to northwest have an average saturated thickness of about 50 ft (Figure 2.4-16). The tributaries to these paleochannels have an average saturated thickness of about 20 to 30 ft. The saturated region is bounded by unsaturated alluvium as shown in Figure 2.4-16.

Unsaturated alluvium has been identified between First and Second Creeks (Figure 2.4-16). This area, and the unsaturated area in the northwest portion of RMA (Sections 22 and 23) were considered in the design of the North and Northwest Boundary Containment Systems. The ends of the North Boundary Containment System soil-bentonite barriers were designed to key into low permeability bedrock highs corresponding to unsaturated alluvium. Likewise, the northeast end of the soil-bentonite barrier at the Northwest Boundary Containment System was designed to key into clayshale bedrock below an area of unsaturated alluvium.

The boundaries of unsaturated areas of alluvium fluctuate because of seasonal water-level variations which average approximately 2.5 ft across the study area. The saturated thickness is generally greatest in late winter and spring and lowest during summer and fall. Near the containment systems the saturated thickness is influenced by the operation of dewatering and recharge wells and the presence of the soil-bentonite barriers. A detailed assessment of stresses imposed on the Unconfined Flow System by the containment systems and the resulting changes in saturated thickness is described in

Task 25 (ESE, 1988f, RIC#89024R02) and Task 36 (ESE, 1988e, RIC#88344R02) Draft Final Reports.

2.4.3.2 Hydraulic Characteristics

Regionally, the water table configuration in the Unconfined Flow System has been relatively stable since 1956. This is probably due to the influence of hydraulic connection with the underlying Denver Formation (May, 1982, RIC#82295R01). Locally the hydraulic characteristics of the Unconfined Flow System and changes in hydrologic stress in the system influence the direction of primary groundwater-flow paths.

Seasonal water-table trends reflect recharge and discharge variations during the year. Generally, the water-table elevations vary seasonally with the highest water levels being observed in the spring of each year and the lowest during the late summer or fall. Seasonal water-table trends were assessed by analyzing hydrograph data (Figure 2.4-18) from wells associated with First Creek, North and Northwest Boundary Containment Systems, off-post area, Western Tier, Southern Tier and South Plants area. These trends are discussed below on an area by area basis.

First Creek: Hydrographs for wells directly influenced by alluvium-stream interaction were analyzed. Seasonal fluctuations for Wells 24106, 24187, 37338, 37343, and 37366 for the years 1986 and 1987 are shown in Figure 2.4-18. The data from the area along First Creek indicate seasonally fluctuating water levels. These fluctuations range from 1.5 ft in the southern on-post area to 3 ft in the northern on-post area. Generally, the highest water levels occur during April and May, and the lowest water levels occur during August and September. Water-level elevations in the late winter months sometimes exceed those of the spring months. This is due to surface infiltration of snowmelt.

North and Northwest Boundary Containment Systems: Water-level data from wells were projected onto a line showing geographic spacing to generate hydrographic profiles. An east-to-west hydrographic profile was constructed approximately 1,100 ft upgradient of the North Boundary Containment System, to assess the seasonal variations of the water table (Figure 2.4-19). This profile illustrates the variations in water levels across Sections 23 and 24. Seasonal water-level fluctuations illustrated on this profile vary between approximately 1 ft at Well 23160 to approximately 5 ft at Well 24113. The water-

level fluctuations observed in Well 24106 illustrate the influence of nearby First Creek. Another hydrographic profile constructed along a southwest to northeast line through sections 23 and 24 illustrates the change in water level across the North Boundary Containment System (Figure 2.4-20). The wells in this profile indicate minimal seasonal variation but show the decrease in water levels across the soil-bentonite barrier due to the dewater and recharging operations.

A third hydrographic profile constructed along a southwest to northeast line approximately 850 ft upgradient of the Northwest Boundary Containment System illustrates minimal seasonal water-table variation (Figure 2.4-21). The profile also shows a decrease in water levels in the vicinity of the Northwest Boundary Containment System dewatering wells relative to water levels in wells southwest of the boundary system.

The water-table elevations across the Northwest Boundary Containment System are relatively constant as illustrated by a fourth profile with a southeast-to-northwest orientation (Figure 2.4-22). This profile shows minimal seasonal variation and a general decrease in water levels across Section 27, following the general bedrock configuration.

Off-post Area: Seasonal water-table fluctuations were assessed by evaluating well hydrographs. Generally, the seasonal fluctuations observed varied from 1 to 2 ft, with more extreme fluctuations observed close to First Creek north of RMA and adjacent to off-post irrigation ditches northwest of RMA. The highest water levels are generally observed in the late winter and spring of each year and the lowest during late summer or fall. This is shown in the seasonal hydrographs for Wells 37308/37309 and 37335, respectively (Figures 2.4-23 and 2.4-24).

Western Tier: Seasonal water table fluctuations in the Western Tier were on the order of 1 to 2 ft, although more significant fluctuations occur in Section 33. Fluctuations of about 5 ft were noted in Wells 04007 and 33002 and up to 16 ft in Well 33018 (CDM, 1986). The latter well is influenced by operations of both the Irondale Containment System and the South Adams County Water and Sanitation District well field near 77th Avenue and Quebec Street. Observation Wells 33002 and 33018 both exhibited a seasonal low in August, which was a result of heavy summer pumping by the sanitation district in addition to the normal seasonal low (CDM, 1986).

Southern Tier: Hydrographs for Wells 02008, 02020, 02026, 02001, 02023, and 02034 were analyzed for seasonal fluctuations and were found to range from 1 to 3 ft. The water levels in wells upgradient of Ladora Lake tended to steadily increase from September and peak in June. The seasonal low occurs in mid-August. Similar seasonal fluctuations were also noted in Ladora Lake and Lake Mary because both interact directly with the water table.

South Plants Area: In the South Plants area, elevations of the groundwater mound fluctuated a maximum of 3 to 6 ft between 1982 and 1986. The largest fluctuations appear to be coincident with the central portion of the mound where the potentiometric surface occurs within the bedrock. This may be a function of either historic recharge from leaking sewers in this area, the intrinsic properties of the bedrock, or both (Ebasco, 1988d, RIC#88286R08).

High water table elevations in the winter and spring months are indicative of increased infiltration of snowmelt and rainfall as well as decreased evapotranspiration. Although the trends presented above may differ somewhat from year-to-year, varying seasonal recharge from direct infiltration of precipitation and from surface water bodies is primarily responsible for the minor seasonal water table fluctuations.

An assessment of hydraulic conductivity was based on the slug test and pumping tests conducted in numerous wells both on-post and off-post. Data from the tests were compiled, evaluated, and reinterpreted as necessary. Results are tabulated in Appendix B.

Values of hydraulic conductivity were determined from slug tests although values derived from slug tests are more variable than those derived from pumping tests. Slug test results apply only to a relatively small area around the well bore and may not represent conditions beyond the immediate borehole. Fast recoveries from the slug tests may not have allowed for successful measurement in highly permeable materials.

Slug test results provided by Zebell et al., (1979, RIC#81266R19) were evaluated and found to be considerably lower than would be expected on the basis of geology. The vast majority of calculations were performed using the Cooper method for confined conditions (Cooper et al., 1967). Seven of the 40 tests performed in the Unconfined Flow System were analyzed with the Bouwer-Rice method (1976) for unconfined conditions. These

results are fairly good approximations and are considered to be representative of the alluvium (Table 2.4-4). These test results were taken from wells completed in Section 24 and are not representative of the site overall. The results are in general agreement with those obtained from pumping tests.

A histogram of hydraulic-conductivity values obtained from slug tests (Figure 2.4-25) shows values which are significantly lower than hydraulic-conductivity estimates from pumping tests. Most of the calculations were performed using the Cooper method for confined conditions. Therefore, slug test results obtained using the Cooper method probably should not be used for site characterization of the Unconfined Flow System. Long-term aquifer tests presented in Appendix B are more appropriate for assessing the hydraulic conductivity of the Unconfined Flow System.

Pumping test results in Appendix B are grouped according to geologic characteristics. The test results indicate that the hydraulic conductivity estimates for alluvial material range from 28 ft/day (1×10^{-2} cm/sec) to 2500 ft/day (9×10^{-1} cm/sec). Only one test has been conducted in eolian sediments. The hydraulic conductivity estimate for this test (11 ft/day, 4×10^{-3} cm/sec) is lower than values measured in coarser alluvium.

The results of aquifer tests conducted in the study area (Appendix B) were used to provide estimates of hydraulic conductivity for different types of sediments, or units, comprising the Unconfined Flow System. Typical values and ranges of estimates are shown in Table 2.4-5.

Unit boundaries, mapped by MKE (1988, Plate 16), were refined by utilizing borehole lithologic descriptions and aquifer test data. In some cases, changes in the water-table gradient were also used for evaluating the boundaries between units with contrasting hydraulic conductivities. Locations of paleochannels were taken from the bedrock map, and channel widths were estimated based on slope changes in bedrock contours and the distribution of coarser fraction sediments (gravel) within the channels. Seven units were defined, including six Quaternary units and one unit of the Denver Formation. For each unit, an expected hydraulic conductivity range and typical value was established (Table 2.4-5). For hydrogeologic units with a substantial number of aquifer tests, typical values given in Table 2.4-5 are the median values of those tests. These units are QT, QA1, QA2

Table 2.4-4 Alluvial Slug Tests Using the Bouwer-Rice Method

Well Number	K (cm/sec)	K (ft/sec)
24126	1.3×10^{-2}	4.0×10^{-4}
24048	2.5×10^{-1}	8.2×10^{-3}
24049	1.1×10^{-1}	3.6×10^{-3}
24084	9.9×10^{-3}	3.0×10^{-4}
24092	6.2×10^{-2}	2.0×10^{-3}
24115	1.1×10^{-2}	4.0×10^{-4}
24129	1.7×10^{-2}	6.0×10^{-4}

K Hydraulic conductivity

Source: ESE, 1988.

Table 2.4-5 Summary of Hydraulic Conductivity Estimates

Lithologic Type	Typical Values (cm/sec)	Range of Estimates** (cm/sec)
QT Terrace Gravels	3×10^{-1}	1×10^{-1} to 1
QA1 Paleochannels in Terrace Gravels	3×10^{-1}	1×10^{-1} to 1
QA2 Paleochannels in Eolian (with gravel)	1×10^{-1}	5×10^{-2} to 5×10^{-1}
QA3 Silty Terrace Gravels & Coarse Sand	8×10^{-2}	2×10^{-2} to 2×10^{-1}
QA4 Paleochannels in Eolian (without gravel)	5×10^{-2}	10^{-2} to 10^{-1}
QE Eolian Deposits	2×10^{-2}	4×10^{-3} to 4×10^{-2}
TKd Denver Fm*		1×10^{-5} to 10^{-3}

* Range of hydraulic conductivity in Denver Fm may be significantly greater where the upper Denver Fm is highly weathered.

** To convert to ft/sec multiply by 3.28×10^{-2}

Source: ESE, 1988.

and QA3. Aquifer test data for the remaining units, particularly data from multiple-well tests, are more limited. In these cases, the range of estimates is based on test results while the typical value reflects the judgment of the hydrogeologists who compiled the information. Distribution of units is illustrated in Figure 2.4-26 (Plate 18). Units are described here in order of decreasing hydraulic conductivity.

QT: Terrace and bench gravels and coarse sands. Coarse sediments comprising terraces and benches of the South Platte River, including Broadway and Louviers Alluviums.

QA1: Gravel and coarse sand which fill paleochannels incised into terrace gravels. Source materials are largely reworked terrace gravels. Based on data from pumping tests, no hydraulic conductivity distinction can be made between channel and non-channel deposits in the QT/QA1 area.

QA2: Coarse sands and gravels present in paleochannels which dissect eolian deposits. These are present in the First Creek and other paleochannels and are thought to be locally derived from surrounding terrace gravels of the Older Slocum and bedrock highs.

QA3: Silty terrace gravels and coarse sand. This unit consists of two sediment types, yielding similar hydraulic conductivity values in pumping tests. The first is the Older Slocum Alluvium, a terrace gravel with an appreciable sand and silt content, present in the north-central RMA. The second is a coarse sand area present between bedrock highs and the First Creek paleochannel. These sands are anomalously coarse-grained compared to the surrounding fine-grained eolian deposits and fine-grained paleochannel fill. They may be present due to a flattening of topography and consequent deposition of coarser sediment in these areas.

QA4: Fine-grained channel fill. This sediment is also present where paleochannels dissect eolian deposits. Source material is fine-grained, hence the channel fill consists of fine sands and silts. No pumping tests are available to assess the hydraulic conductivities of this unit; however, based on lithologic character, this sediment is assumed to be only slightly more permeable than surrounding eolian deposits.

QE: Eolian and alluvial deposits comprised of a thin cover of fine-grained eolian sands, silts and clays. Hydraulic conductivity is based upon one pumping test, performed in fine-

grained sediment. Conductivity estimated by this test was judged to be near the lower end of the likely range of values.

TKd: Denver Formation underlying unsaturated alluvium. The water table in these areas lies below the top of the bedrock. The bedrock consists of variable lithologies but generally has much lower hydraulic conductivity than Quaternary units.

Specific yield, or the amount of water released by gravity in an unconfined aquifer during a unit drop in potentiometric level, was also evaluated during this study. The specific yield for the Unconfined Flow System was calculated from the pumping-test data and the computed values range from 0.01 to 0.05. In areas corresponding to buried paleochannels, coarser sediments are predominant and higher values of specific yield range from 0.23 to 0.25. These values fall within the typical specific-yield ranges for the alluvium. Representative specific yield values for fine-grained to gravelly sands range from 0.10 to 0.30, and for fine to clayey sands range from 0.01 to 0.20 (Walton, 1987).

2.4.3.3 Unconfined Flow System Recharge

Recharge to the Unconfined Flow System occurs at many locations within the study area through both natural and manmade mechanisms. Recharge originates from a variety of sources including infiltration of precipitation, streams, manmade systems and natural basins, off-post irrigation, and seepage from the Denver aquifer. The section describes the types of recharge, the areas where it occurs, and the estimated quantities. Recharge is estimated within the region bound by the Highline Canal, Sand Creek, South Platte River and Second Creek.

Investigations prior to 1983 identified recharge areas but generally did not make estimates of recharge rates. Values presented in Table 2.4-6 have been modified as needed from the original estimates if the original study area is different than the study area used for this report. For example, the estimate of irrigated acreage obtained by MKE (1987) was adjusted even though the estimated recharge per unit area remained the same. Many of the recharge components are seasonal in nature.

Table 2.4-6 Sources of Recharge to the Unconfined Aquifer
(Page 1 of 2)

Source	Reference	Estimated Recharge Value (Acre-Feet/Year)
Infiltration of Precipitation	MKE, 1987	740
First Creek (on-post)	ESE	300
First Creek (off-post)	ESE	316
Basin A	ESE MKE, 1987	9.6 (max) 20
B	MKE, 1987	4
C	MKE, 1987	1.8
Sewage Treatment Plant	ESE	0
Lower Derby Lake	ESE	480
Upper Derby Lake	ESE	highly variable
Havana Pond	ESE	1,300
Uvalda Interceptor	ESE	360
Rail Classification Yard	MKE, 1987	13
Sand Creek Lateral (short reach near South Plants)	ESE	20
Fulton Ditch	Fulton Ditch Co., 1988 Water Year 1985 Water Year 1986	 4,010 4,030
Burlington Ditch* (leakage = 30% of flow)	FRICO, 1988 Water Year 1986	 5,300
O'Brian Canal* (leakage = 25% of flow)	FRICO, 1988 Water Year 1986 Water Year 1987	 10,400 15,800

Table 2.4-6 Sources of Recharge to the Unconfined Aquifer
(Page 2 of 2)

Source	Reference	Estimated Recharge Value (Acre-Feet/Year)
Highline Lateral	ESE RCI, 1982**	900 489
North Bog	ESE	190
Irrigation	MKE, 1987	6,550

* Estimates are for the entire length of the canals, not just the study area.

** Calculated from 1979 and 1980 data for the entire length of the lateral. Value does not consider local inflows, therefore the actual value may be larger.

References: MKE (Morrison-Knudsen Engineers, Inc.). 1987. Preliminary Recharge Estimates for RMA Regional Flow Model, Final Version; MKE, 7/16/87.

FRICO (Farmer's Reservoir and Irrigation Company). 1988. Personal Communication.

Fulton Ditch Company. 1988. Personal Communication.

RIC (Resource Consultants, Inc.). 1982. Surface Water Hydrogeologic Analysis, Rocky Mountain Arsenal.

HLA (Harding Lawson Associates, Inc.). 1988, written communication.

Source: ESE, 1988.

Recharge estimates presented in this report should be considered initial values that are subject to revision and refinement as Feasibility Studies proceed. In many cases, such as recharge from precipitation, recharge varies substantially throughout the season. Seasonal variations are not quantified in this report on a regional basis.

Because many estimates are based on important assumptions that cannot be readily assessed with available data, accuracy and reliability of estimates cannot be assessed. Detailed analysis of contaminant migration conducted as part of Feasibility Studies may require that uncertainty of estimated recharge be established quantitatively. If required, additional analysis and possibly data collection would be needed.

Infiltration of Precipitation: MKE (1987) conducted a detailed investigation of infiltration at RMA. This study concluded that precipitation rarely percolated directly down to the Unconfined Flow System. Recharge related to infiltration is highly variable and dependant on a number of unrelated factors. However, precipitation can accumulate in ditches and other depressions and then infiltrate to the Unconfined Flow System. MKE (1987) concluded that approximately 0.25 inches of water per year recharge to the water table from infiltration of precipitation.

The MKE estimate of recharge from precipitation was based primarily on results of a soil infiltration and drainage model. Infiltration was simulated by the Green-Ampt equation. Drainage was simulated by using a mass balance approach with a layered soil. Evapotranspiration was simulated with an empirical method. The model was applied to various RMA soils for the 1972 through 1981 period, and resulted in estimates of average annual recharge that varied spatially from 0 to 0.88 inches per year. Nonhomogeneties in soil properties, seepage from borrow pits and other points of surface-water collection, and other factors were not simulated. To account for these factors, MKE assumed that net recharge from precipitation equaled 0.25 inches per year. In unvegetated areas, such as bare ground in Basins A and C, MKE assumed recharge equalled 1.5 inches per year.

Streams: First Creek is the only well defined, natural surface water channel crossing RMA, entering through southeast Section 8 and exiting to the north through Section 24. Analysis of data obtained from October 1985 to November 1987 indicate that it is a losing stream along most of its course with an average net loss of 300 ac-ft/yr. This

estimate is derived from the difference in flow measurements at gaging stations located at the southeast corner of RMA, the north boundary, and Highway 2.

Although First Creek experiences an overall net loss of water, some segments of First Creek may lose water to or gain water from the Unconfined Flow System. Whether First Creek is gaining or losing water depends on the quantity of baseflow and water-table elevations in a specific area.

Manmade Systems and Natural Basins: Unlined irrigation canals and man-made lakes are major sources of surface water recharge to the Unconfined Flow System. These include the Burlington Ditch and O'Brian Canal (northwest of the site), Highline Canal, Upper and Lower Derby Lakes, and Havana Pond. The recharge rates from these sources were estimated on the basis of available data such as hydraulic conductivity, water-level elevations, and baseflow measurements. These sources of recharge comprise greater than 90 percent of the total recharge from surface water bodies. Data used to estimate these rates are provided in Appendix B.

External stresses to the Unconfined Flow System have caused significant water table and gradient fluctuations over time. From late 1959 until the early 1970's, local water-table fluctuations occurred as a result of periodic storage of large volumes of wastewater (1956-1957) and fresh water (1963-1974) in Basin C. Currently, stresses include the presence and operation of boundary containment systems, recharge from surface water features, and withdrawal from wells.

A significant departure from the regional trend in the groundwater flow direction is observed in the South Plants area, where groundwater flows radially outward from a water-table high. This feature has been referred to as a groundwater mound in previous investigations (May, 1982, RIC#82295R01). This mound has been in existence at least since 1957.

The location of the mound corresponds with the east-to-west trending topographic high and underlying bedrock high. The bedrock high is composed of low permeability claystone and poorly sorted volcanoclastic sediments that impede vertical groundwater flow and may contribute to groundwater mounding. Alluvial deposits in the South Plants area are low permeability eolian and alluvial silts, sandy silt, and silty clay. These sediments slow

groundwater flow relative to adjacent areas and slow the rate of decline of the water table.

The mound probably has been enhanced by recharge from leaking pipes and sewer lines, the collection of local runoff in low-lying areas and various other activities involving water transmission or collection within the South Plants area. A major leak in such systems was identified and corrected in 1980. Water levels beneath South Plants peaked and began to decline after the leak was repaired (May, 1982, RIC#82295R01). Water levels in the mound area have generally declined by 1 to 2 ft between 1982 and 1986. Hydrologic conditions in the South Plants area are detailed in the forthcoming South Plants SAR.

Irrigation: Recharge from irrigated and subirrigated areas was estimated using generally accepted assumptions for conditions in the South Platte River Valley. These include an assumed average water application rate of 4.2 ft/yr, 45 percent of which infiltrates to the water table (Hurr, et al., 1975). The resulting net infiltration rate of 1.9 ft/yr was multiplied by the land area under cultivation. This area of cultivation was determined by analyzing a 1984 LANDSAT photograph and computing the irrigation recharge rate. Based on these parameters, a value of 6,550 ac-ft/yr was estimated for irrigation recharge.

Denver Aquifer: Regionally, groundwater in the Denver aquifer flows laterally to the north-northwest. The formation provides a component of recharge to the Unconfined Flow System. Such recharge is expected to be concentrated where sandstones or fractured rocks subcrop against the overlying alluvium. These subcrop areas are oriented along northeast to southwest trends, parallel to the regional strike of bedding. A Denver Formation sandstone subcrop map is shown in Plate 7.

Recharge from the Denver aquifer was estimated by HLA (1989) by assuming a hydraulic gradient of 0.0033 for lateral flow from the Denver aquifer into the Unconfined Flow Systems and a value of 3.0 ft/d for hydraulic conductivity sandstone. Darcian velocity was 0.01 ft/day. Recharge in areas without subcropping sandstone was estimated using an assumed value of 0.3 ft/d for hydraulic conductivity and 0.0033 hydraulic gradient. These estimates represent large simplifications of complex heterogeneities in hydraulic conductivity and hydraulic gradient of the Denver aquifer. Therefore, it should be considered an initial estimate subject to substantial refinement when characterizing

hydrogeologic conditions of specific areas. Because uncertainty of the estimate is so large, no value is reported in Table 2.4-6.

2.4.3.4 Unconfined Flow System Movement

The potentiometric-surface map indicates that the primary lateral groundwater flow direction in the study area is toward the north and northwest. The Third Quarter FY87 water-table contour map (Figure 2.4-1) was used to assess magnitudes and directions of hydraulic gradients within the study area. Variations in hydraulic gradients between areas are largely a function of saturated alluvium thickness and hydraulic conductivity. Where saturated alluvium is thin, hydraulic gradient tends to be influenced by the configuration of the bedrock surface.

Low gradients occur in areas containing coarse-grained sediments with high hydraulic conductivity. The lowest gradients in the study area occur west of D Street, between Basin F and the North Boundary Containment System (Section 23). The average hydraulic gradient in this area is 0.002 ft/ft; however, local gradients have been reported as low as 0.0007 ft/ft (ESE, 1988e, RIC#88344R02). Low gradients also occur in highly permeable gravels in the western tier, and along the South Platte River. The average gradients were estimated to be 0.004 ft/ft in these areas.

On-post, average hydraulic gradients of 0.006 and 0.009 ft/ft were estimated to the east along First Creek and south-central part of RMA, respectively. Off-post, between the RMA boundary and the South Platte River, the average gradient is 0.008 ft/ft.

The steepest gradients in the area occur where groundwater is moving through less permeable alluvium, or through the Denver Formation underlying unsaturated alluvium. These conditions are prevalent in, but not limited to, the region northwest of Basin F (Section 22) and the area upgradient from the North West Boundary Containment System (Sections 27, 34, and 35). Hydraulic gradients range from 0.013 to 0.024 ft/ft in these areas. A summary of hydraulic gradient magnitudes calculated for selected areas is presented in Table 2.4-7.

Table 2.4-7 Calculated Hydraulic Gradients

Area	Hydraulic Gradient	
	(ft/mi)	(ft/ft)
First Creek (on-post)	32	0.006
Sections 11 and 12	48	0.009
Basin A Neck	70	0.013
Basin A	21	0.004
Western Tier and Along South Platte River	23	0.004
Basin F to RMA North Boundary	11	0.0002
RMA North Boundary to South Platte River (off-post)	40	0.008

ft/mi = foot per mile

ft/ft = foot per foot

Source: ESE/HLA, 1988.

The regional change in gradient directions and magnitudes between the central and western portions of the study area are attributed to the contrast between highly permeable gravels in the west and lower permeability eolian deposits and bedrock in the central area. Additional variations in the regional north-northwest trend are also apparent in local areas in close proximity to:

- o Paleochannels;
- o Surface water impoundments;
- o Areas of unsaturated alluvium; and
- o The North and Northwest Boundary Containment Systems.

These deviations are generally the result of enhanced groundwater recharge and/or discharge associated with surface water features, or refraction of groundwater flow lines at the boundaries between lithologic units with contrasting hydraulic conductivity (e. g., between alluvium and Denver Formation). Containment system dewatering and recharging operations may also cause deviations in regional trends.

The Third Quarter FY87 water-table map was used to assess groundwater flow directions and hydraulic gradients in the Unconfined Flow System (Figure 2.4-1). Areas of unsaturated alluvium, where the water table occurs in the Denver Formation, are shown by the stippled pattern in Figure 2.4-1. Under these conditions, the groundwater flow direction is basically the same as in the alluvium. However, hydraulic gradients in the upper Denver Formation are steep due to low permeability. These gradients range from 0.007 to 0.019 ft/ft in the upper Denver Formation as compared to 0.002 to 0.009 ft/ft in areas of saturated alluvium.

2.4.3.5 Unconfined Flow System Discharge

Although First Creek experiences an overall net water loss to the Unconfined Flow system, it is probable that some stream segments may gain water from the Unconfined Flow System. Whether First Creek is gaining or losing water depends on the quantity of baseflow relative to water-table elevations.

Discharge from the Unconfined Flow System to the Denver Formation may occur where water levels in the alluvium are higher in elevation than potentiometric heads in

underlying Denver Formation sandstones or fractured rocks. The magnitude of such downward vertical leakage is dependent on the head difference and the effective vertical hydraulic conductivity of lower permeability units within the Denver Formation.

Discharge from the Unconfined Flow System occurs at several different locations within the study area. This section describes the discharge areas and provides estimated discharge quantities based on the current investigation and work performed by previous investigators.

Several of the larger surface water impoundments located in the RMA Lower Lakes area appear to be recharged by groundwater. Ladora Lake and Lake Mary, as well as the Rod and Gun Club Pond, occur at or slightly below the regional water-table elevation. Estimates of groundwater discharge to Ladora Lake and Lake Mary, collectively, vary from 67 ac-ft/yr (Table 2.3-4) to 360 ac-ft/yr (MKE, 1987). Discharges to the Rod and Gun Club Pond is assumed to be approximately 15 to 25 ac-ft/year. Upper Derby Lake, which is typically dry, is subirrigated and evapotranspiration in this area accounts for discharges from the Unconfined Flow System at approximately 30 ac-ft/year. Discharge due to evapotranspiration is believed to occur in areas where the water table is within 5 ft of the ground surface (RCI, 1982b, RIC#82096R01).

Regional discharge for the Unconfined Flow System is the South Platte River. Groundwater discharge volume estimates are based on previous RMA aquifer studies (Konikow, 1975; MKE, 1987) and recent investigations. Values obtained are sensitive to hydraulic-gradient estimates, average flow system thicknesses and hydraulic-conductivity values. Estimated discharge volumes to the South Platte River range from 28,400 ac-ft/yr to 56,600 ac-ft/year. The low value corresponds to recent conditions when recharge was substantially less than historically accurate. The high value corresponds to historical conditions. The average value is 46,500 ac-ft/year. A summary of the methods and assumptions made to estimate these rates is provided in Appendix B.

Pumping wells also obtain water from the Unconfined flow System. Six municipal supply wells owned by the South Adams County Water and Sanitation District (SACWSD) withdraw water at a rate of approximately 3,900 acre-ft/yr (John Hamilton, Muller Engineering Company, 1988, oral communication). There are three active pumping wells located in Section 4. The wells were originally installed to supply water to the lakes and are now

turned on once a month for maintenance purposes. Pump capacity is 500 gpm. There are no known points of spring discharge from the Unconfined Flow System on-post.

2.4.3.6 Vadose Zone

Although the vadose zone is not part of the Unconfined Flow System, the hydraulic characteristics of the vadose zone influence the character of surface water/groundwater interactions. It is through this zone that rainfall and surface fluids from lakes, ponds and streams intermittently percolate to the outer table.

The interaction between surface and subsurface fluids is significantly impacted by the thickness of the vadose zone. In areas such as the Western Tier of RMA where the vadose zone is thick, and surface water/groundwater interactions are believed to be of minor importance. In areas such as Lake Mary where the aquifer system appears to intersect the surface of the lake, the vadose zone is absent and direct hydraulic communication exists between surface water and groundwater.

2.4.4 Interactions Between Surface and Groundwater

The surface water and groundwater at RMA are not separate systems and interactions may be significant, depending on location and time of year. The objective of this section is to identify and quantify the interactions between surface water and groundwater. A number of surface water and groundwater parameters were examined including precipitation, infiltration and percolation, evaporation and transpiration, and site characteristics. Unconfined Flow System parameters investigated include aquifer composition, water-table elevation, saturated thickness, flow direction, bedrock elevations and water quality. The surface water/groundwater interactions involve localized study units. These study units were selected on the basis of data availability, extent in relation to RMA, and the relative importance as a contaminant source or of contaminant pathway.

The study units are: Upper Derby Lake, Lower Derby Lake, Ladora Lake, Lake Mary, Havana Pond, Basin A, Basins B through E, Basin F, Uvalda Interceptor, Highline Lateral, the Sewage Treatment Plant, First Creek and the North Bog (Figure 2.3-2). The lakes and streams were selected because abundant surface water data is available and because of

their potential as recharge sources. Criteria for remaining study unit selection is based on groundwater data availability and contaminant transport concerns.

Data utilized in study unit interpretation include well data, surface water monitoring data and climatic data. Well data are primarily concentrated at the north and northwest boundaries and downgradient from the primary contaminant sources. Areas with sparse well data, along the southern and western sections of RMA, affect the evaluation of Havana Pond, Uvalda Interceptor, Highline Lateral, and portions of First Creek. Figure 2.3-2 shows the surface water monitoring site locations. These sites are numerous for the lower lakes region, but sparse for the disposal basins area. Consideration is also given to areas of known groundwater and surface water contamination including Basins A through F, the South Plants area, the Sewage Treatment Plant and the North Boundary Area.

Once the individual study units were delineated, surface water/groundwater interactions for each were evaluated. This included location and description of each study unit, evaluation of surface water/groundwater interactions, a quantitative evaluation of this exchange, and an evaluation of unique constraints, driving forces, and variabilities associated with the interaction process. No attempt is made to address historic conditions affecting the groundwater regime.

2.4.4.1 Upper Derby Lake

Upper Derby Lake is the easternmost of the lakes, located in the southeast quadrant of Section 1 and the southwest quadrant of Section 6 as shown in Figure 2.3-3. Embankment elevation is 5,262 ft msl and lake bottom, outlet and overflow elevations are 5,247, 5,250 and 5,260 ft msl, respectively, with a maximum lake depth of 13 ft at overflow stage.

Water balance calculations illustrate an average loss of 3.5 acre-feet per month (ac-ft/mo) from October 1, 1985 through February 28, 1986. The rate of loss varies occasionally. The water-table elevation for Well 01044 near the lake averaged 5,247.5 ft msl for 1986 and 1987 with a range of 4.6 ft. The groundwater level averaged 5,249.4 ft msl when Upper Derby Lake contained water (up to August 12, 1986), declining to 5,246.5 ft msl when the lake was dry. From June 1986 to November 1987, Upper Derby Lake was

predominately dry. Under these conditions, the lake bed acts as a groundwater discharge area where groundwater is sufficiently close to the surface to subirrigate the lake bed. Groundwater reserves are subsequently affected by evapotranspiration.

Evapotranspiration from the lake bed was estimated assuming an irrigation requirement calculated using the Blaney-Criddle method (SCS, 1970). Pasture grass was selected for evapotranspiration calculations and the average annual irrigation requirement is 20.38 inches per year. Assuming an average water-table elevation of 5,246.45 ft msl and a 5 ft rooting depth, an area of 17.4 acres was obtained from the stage area curve for an elevation of 5,251.55 ft msl. The estimated annual total evapotranspiration loss is estimated to be 29.6 ac-ft/yr.

To summarize, Upper Derby Lake recharges the groundwater when full and receives groundwater discharge via subirrigation when dry. A groundwater recharge rate of 3.5 ac-ft/mo was estimated for the periods when the lake contained water and a groundwater discharge rate of 2.5 ac-ft/mo was estimated for the periods when the lake was empty.

2.4.4.2 Lower Derby Lake

Lower Derby Lake is located between Upper Derby and Ladora Lake in the southwest quarter of Section 1 (Figure 2.3-3). The embankment elevation is 5255.0 ft and the lake bottom elevation is 5230.5 feet msl. The sluice gate outlet and overflow elevations are 5231 and 5252 ft msl, respectively. At overflow stage the maximum lake depth is 22.5 ft and the volume is 1016 ac-ft.

Data from four wells (01027, 01049, 01024, and 12008) were used in the evaluation of surface water/groundwater interactions. Wells 01049 and 01027 are located to the north of Lower Derby Lake, Well 12008 is located to the south, and Well 01024 is located downgradient near the southwest corner of the lake. Quarterly groundwater elevation data for 1986 and 1987 were available for all of the wells except 12008 which was measured only once (Table 2.4-8). Lower Derby Lake overlies eolian deposits. Water table gradients are 0.0009 ft/ft at the east and 0.007 ft/ft at the west end of the lake.

Table 2.4-8 1986 and 1987 Water-Level Data for South Lakes Wells

Well #	Range of Elevations ¹	1986-1987 Mean Elevation ¹
01049	5244.7 - 5247.5	5246.1
01027	5244.3 - 5249.4	5246.4
01024	5234.7 - 5235.6	5235.1

¹ feet above mean sea level

Source: ESE, 1988.

Water balance calculations indicate an average loss of 39.7 ac-ft/mo. Figure 2.4-27 demonstrates the correlation between lake loss and lake stage. The linear regression equation that best describes this relationship is $Y = 17.67x - 234.7$, where Y = monthly loss in ac-ft and x = lake stage in feet. Extrapolating the regression equation to determine the stage at which water loss is zero yields a stage of 13.25 ft. This equals a lake surface elevation of 5244.3 ft msl, which corresponds with the extrapolated water-level contour of 5245 ft msl. This contour passes beneath the middle of Lower Derby Lake on the Third Quarter FY87 water table map.

Groundwater recharge was evaluated by constructing water level hydrographs for nearby wells. Two upgradient well hydrographs (01027 and 01049) project water levels equal to the lake level. Rises in lake levels produce corresponding rises in groundwater levels. This effect is present, but not as pronounced in downgradient Well 01024, paleochannel.

In summary, Lower Derby Lake represents an aquifer recharge area. Lake losses averaged 39.7 ac-ft/mo from October 1985 to November 1987. Losses increase linearly above a lake-surface elevation of 5244.3 ft. The rate of loss changes 17.6 ac-ft/mo for each foot of stage change. Mass-balance results were consistent with evaluating real time and extended well response evaluations.

2.4.4.3 Ladora Lake and Lake Mary

Ladora Lake and Lake Mary interact with the groundwater in a similar manner. Ladora Lake lies to the west of Upper and Lower Derby Lakes in the southwest quadrant of Section 2 (Figure 2.3-3). The embankment and minimum bottom elevations are 5225 and 5,203.5 ft msl, respectively. Ladora Lake overflows when the surface water elevation exceeds 5,221.0 ft msl for a maximum overflow depth of 17.5 ft and volume of 366 ac-ft. Ladora Lake does not contain a sluice-gate outlet and the only outlet is the overflow at the south end of the embankment.

The primary inflow to Ladora Lake occurs as releases from Lower Derby Lake through Ladora Weir between July and October. Water is added to Ladora Lake as necessary to maintain an adequate water supply for irrigation and process water use. There were three releases each for WY86 and WY87 ranging between 10.4 and 82.2 ac-ft per release.

Lake Mary is the western most lake in the chain and is located below the Ladora Lake embankment in the west side of Section 2. The area of Lake Mary, measured from an aerial photograph, is 8.1 acres. Lake Mary overflows at an elevation of approximately 5203.9 ft msl. Although the Lake Mary embankment contains an outlet structure, the overflow spillway was the only outlet utilized during the monitoring period. Overflow, evaporation and seepage account for water losses from the lake. Groundwater discharge, limited local runoff, and direct precipitation are the only inflows.

Both Ladora Lake and Lake Mary have staff gages read on a weekly basis to determine lake level fluctuations. Both lakes have relatively minor monthly water-level fluctuations; 1.0 and 1.52 ft, respectively.

There are a number of wells located upgradient and downgradient from the lakes. Upgradient Wells 02023, 02001 and 02034 are oriented north-south upgradient from the northeast end of the lakes and downgradient from the South Plants area. Wells 02020 and 02026 are upgradient at the southeast end of the lakes near the Irondale paleochannel. Well 02008 is the downgradient monitoring well located a short distance northwest of Lake Mary. Figure 2.4-28 displays the water levels for the wells and lakes for WY86 and WY87. Water levels for Well 02020 closely reflect Ladora Lake levels. Further upgradient, water levels in wells deviate from lake levels.

Consistent seasonal fluctuations are exhibited by water levels measured for the lakes, in upgradient Wells 02026, 02001, and 02020 and downgradient Well 02002. The water levels in the wells upgradient from Ladora Lake tend to steadily increase from September through the spring, peaking in June. A sharp decline follows, terminating with a seasonal low in mid-August.

Water-balance calculations indicate that Ladora Lake and Lake Mary gained an average of 4.2 and 1.2 ac-ft/mo respectively, over the monitoring period. However, these values are misleading, because frequent overflow volumes are included in the unaccounted loss value. Unaccounted loss value is usually assumed to be an estimate of groundwater recharge. Ignoring unaccounted loss values calculated for those months when overflow occurred, water balance calculations indicate that Ladora Lake and Lake Mary gained an average of 14.0 and 1.4 ac-ft/mo, respectively, through the groundwater discharge. These values are more representative of groundwater discharge into the lakes.

Water losses through the embankment have occurred on the west side of the lake. Water-balance calculations show that groundwater discharge into the lake exceeds lake losses through the embankment by an average of 14.0 ac-ft/mo. The Third Quarter FY87 water-level map (Figure 2.4-1) shows that the Ladora Lake elevation of 5220.3 ft msl was below the extrapolated groundwater elevation on its east side and above the extrapolated groundwater elevation on its west side. This situation is true also for Lake Mary (Figure 2.3-5).

2.4.4.4 Havana Pond

Havana Pond is a stormwater retention pond located near the center of Section 11 (Figure 2.3-3). The embankment elevation is 5,258 ft msl and there are overflow spillways located at both ends of the embankment, at elevation 5,256 ft. At overflow, the pond has an estimated area of 77 acres and volume of 444 ac-ft. Havana Pond contains a sluice-gate outlet structure which was not operating during the monitoring period. Water can be released from Havana Pond into Sand Creek Lateral to prevent overflow.

Water enters Havana Pond through the Havana and Peoria Interceptors. The interceptors are conduits for stormwater drainage from industrial and/or commercial areas to the south off-post. Flows range from 0 to 230 cubic feet per second (cfs) for Peoria Interceptor and from 0 to 677 cfs for Havana Interceptor. The average monthly inflows from Havana and Peoria Interceptors have been 98 and 12 ac-ft/mo, respectively. These flows are expected to increase as the off-post drainage area to the south is developed.

There are three monitoring Wells, 11007, 11008, and 11002 in the vicinity of Havana Pond (Figure 2.3-3). The water level in Well 11002 has been measured regularly, but the levels in Wells 11007 and 11008 have only been measured once or twice. There is a head difference between the water levels in the upgradient Wells 11008 (5,239.19 ft mgl) and Well 11002 (5,236.8 ft msl). The water level in downgradient Well 11007 was approximately 10 ft lower (5229.12 ft msl). These water levels equate to an average gradient of 0.009 ft/ft between the wells.

Water-balance calculations for Havana Pond indicate that virtually all water that enters the pond infiltrates into the subsurface. The average monthly loss was calculated to be

108.3 ac-ft/mo. To verify the interactions between Havana Pond and the underlying groundwater, a regression analysis was performed. Pond losses and water-surface elevations were estimated based upon the groundwater elevation in Well 11002. Using these two variables, groundwater elevations were predicted with a resulting correlation coefficient of 97.5 percent. The predicted and observed groundwater elevations are given in Figure 2.4-29. This Figure also provides Havana Pond surface elevations and monthly precipitation depths for comparison with the water-table elevations. On average, the groundwater elevation is 8.87 ft lower than the pond surface elevations.

The loss rate as a function of pond stage or water level was evaluated. Because stage variations frequently occur over a short period of time, the evaluation of pond losses was done on a weekly basis from October 1985 through December 1986. The weekly losses were converted to ac-ft/mo and compared with stage in Figure 2.4-30. A curve approximating this stage/loss relationship is also given in this figure. The equation for this curve is:

$$Y = 9.16e^{1.136x}$$

Where Y = the loss rate (ac-ft/mo), and x = the Havana Pond stage (ft). This indicates that losses increase exponentially with increased pond stage.

2.4.4.5 Basin A Drainage - Basin A

Basin A, a portion of the Basin A Drainage system, is located in the west-central portion of Section 36 at RMA (Figure 2.4-31) in a natural depression. There are two primary surface water bodies located in Basin A. The first is the old lime settling basins, and the second is a shallow pool located near the center of Basin A. The ground-surface elevations range from approximately 5,240 ft msl at the basin boundaries to approximately 5,230 ft msl in the center. The estimated areal extent of Basin A is 127 acres, and the average surface elevation is 5,235 ft msl. Surface water inflows from the South Plants area entering a lime settling pond via a culvert beneath December 7th Avenue. Overflow from the lime settling basins flows north toward a small pool near the center of Basin A. Monthly readings, taken from October 1985 through November 1987, measured flow volumes ranging from 0.1 to 4.3 ac-ft/mo resulting in an annual average inflow of 9.6 ac-ft/yr.

Seasonal runoff into Basin A, originating in the South Plants area, was estimated based on monthly runoff values over a 32-year period from 1950 through 1982. The average annual runoff volume entering Basin A was estimated to be 7.1 ac-ft. Average surface water inflowing to Basin A from runoff and culvert discharge is approximately 16.7 ac-ft/yr (RCI, 1982b, RIC#82096R01).

Five upgradient and seven downgradient wells have been selected to describe GW/SW interactions within Basin A Drainage (Figure 2.4-31). Water-level data collected from these wells in 1986 and 1987 are summarized in Table 2.4-9. Depth to groundwater ranges over the area from 3.5 ft in Well 36082 to 16.7 ft in Well 36060 although depths as shallow as 0.3 ft were recorded. The alluvium is unsaturated in the eastern and northern portions of Section 36 where the underlying bedrock surface is shallow.

Five wells associated with the lime settling basins were evaluated. Well 36109 is approximately 100 ft east of the settling basins (Figure 2.4-31) and has an average water elevation of 5,247.3 ft msl. In March 1985, the water-surface elevation within the pond was 0.9 ft above the average groundwater table identifying the lime settling basins as potential groundwater recharge sources. With increasing distance from the settling basins, the influence of surface water recharge on groundwater elevations becomes less significant. Well 36060 displays a relatively good correlation of fluctuations between measured pond inflows and the groundwater table. Wells 36060 and 36109 display the largest groundwater level fluctuations of all wells in this area (Table 2.4-9). No recharge effect from the lime pond was observed for groundwater levels in the two farthest wells (36076 and 36065). Well 36054 is close to the pond, but is located upgradient and shows no indication of surface water impact.

In the vicinity of the central pool, there is a downgradient well (36093), approximately 150 ft to the northwest of the pool. The surface water elevation in the pool was 5,230.8 ft msl in March 1985, while the corresponding water-table elevation was 5,230.1 ft msl indicating a close relationship between the groundwater and surface water levels.

Five monitoring wells (36081, 36082, 36017, 35047 and 35065) are located along the main dry drainage ditch north of the pool. Minor drainage ditches channel water from the central pool into the main ditch when the pool is overflowing. There is no correlation

Table 2.4-9 1986 and 1987 Water-Level Data for Basin A Wells

Well #	Range of Water Table Elevations ¹	1986-1987 Mean Elevation ¹
36054	5251.3 to 5252.9	5251.9
36060	5239.2 to 5242.4	5240.3
36065	5235.5 to 5238.6	5237.1
36076	5238.5 to 5240.7	5239.8
36109	5243.9 to 5248.8	5247.3
36017	5226.0 to 5227.4	5226.8
36013	5226.9 to 5228.1	5227.5
36081	5228.3 to 5230.0	5229.3
36082	5229.4 to 5231.3	5230.2
36093	5229.6 to 5230.9	5230.2
35047	5214.8 to 5216.9	5215.8
35065	5220.1 to 5221.3	5220.5
Lime Pond Water Level (March 1985)		5248.2
Central Pool Water Level (March 1985)		5230.8

¹ feet above mean sea level

Source: ESE, 1988.

between precipitation and groundwater level fluctuations in these wells indicating minimal recharge from the surface drainage. This may be due to the low soil infiltration rate for the Basin A area, estimated by RCI (1983, RIC#83235R01) to be 0.01 in/hr, and/or limited runoff.

Mass balance calculations were utilized to evaluate surface water impact on groundwater for the lime settling pond and for the central pool. For the mass balance calculations it was assumed that the water bodies maintained a constant storage volume. Transpiration, local runoff and overflows were neglected. Mass balance calculations estimated recharge as inflow plus precipitation minus evaporation. Average annual recharge from the lime settling ponds is 8.0 ac-ft, calculated on the assumption that all inflows, diminished by evaporation loss, contribute to groundwater recharge.

In the absence of runoff inflows into the central pool, an estimated monthly discharge of 0.44 ac-ft from the groundwater into the pool was required to meet the evaporative demand. During months with high inflow rates, a recharge from the pond to the groundwater can be expected. The groundwater conditions in Basin A are complex, because the Confined and Unconfined Flow Systems appear to be hydraulically connected with recharge/discharge relationships changing throughout the basin.

Water quality data in the lime settling basins area also indicate the basins act as a recharge source. Dicyclopentadiene, ethylbenzene, and organosulfur compounds were all detected in the lime pond waters with lower concentrations in the adjacent wells. These contaminant concentrations decrease downgradient and are absent in Well 36109, located to the east of the lime settling basins. This also indicates that the lime pond may be a source, given a northwest groundwater flow direction.

The water quality of the central pool indicates the presence of fewer contaminants than the lime settling basins but at higher concentrations. Higher contaminant concentrations may indicate either the discharge of contaminated groundwater into the pool or concentration increases due to evaporation, or both.

In conclusion, the analysis of surface water elevations and groundwater elevations, water-balance evaluations, and contaminant concentrations indicate two areas of contrasting surface water/groundwater interactions within Basin A. The lime settling basins are

recharging the groundwater at an approximate rate of 8 ac-ft/yr and the central pool is receiving groundwater discharge.

2.4.4.6 Basin A Drainage - Basins B, C, D, and E

Basin B is located in the northeast corner of Section 35, and Basins C, D, and E are located in Section 26 on RMA (Figure 2.4-31). These basins are natural depressions dammed for use as wastewater storage lagoons.

Basin B

Basin B is approximately two acres in area with a perimeter elevation of 5,222 ft msl, and a bottom elevation of 5,216.4 ft msl. The ground surface and associated surface water drainages slope northwest. Surface water runoff enters the basin from a drainage ditch connected to Basin A. Another drainage channel directs overflows from Basin B, to the northwest, into Basin C.

Sufficient data were not available to estimate the runoff into Basin B. Basin B is a dry grassland where ponded surface water is generally observed in low areas following heavy rains. Basin B overlies a bedrock paleochannel originating in Section 36 and extending to the northwest. The Unconfined Flow System is influenced by this paleochannel which represents an important groundwater pathway in this area. The direction of flow in this pathway is consistent with the regional groundwater flow direction.

There are four alluvial monitoring wells in the vicinity of Basin B, three upgradient wells (35047, 35065, and 35069) and one downgradient well (35007).

The Third Quarter FY87 water-table elevations beneath Basin B range from 5,206 to 5,212 ft msl. Water table fluctuation in 1986 and 1987 ranged from 1.2 ft in Well 35065 to 4.5 ft in Well 35047 (Table 2.4-10). Based on the bottom elevation of Basin B, periodic surface water accumulations in the basin are 4.5 to 10.5 ft above the groundwater table. Considering fluctuations of 4.5 ft in the upgradient Well 35047, the groundwater table may come into direct contact with the basin.

Table 2.4-10 1986 and 1987 Water-Level Data for Basin B

Well #	Range of Water Table Elevations ¹	1986-1987 Mean Elevation ¹
35047	5,215.1 to 5,219.6	5,216.4
35065	5,220.1 to 5,221.3	5,220.5
35069	5,220.2 to 5,221.8	5,221.0
35007	5,186.8 to 5,190.8	5,189.5
Basin B	Approximate bottom elevation	5,216.0

¹ Feet above mean sea level

Source: ESE, 1988.

Groundwater level fluctuation plots in upgradient and downgradient wells generally display the same pattern. Surface water storage within the basin did not affect the downgradient well. Major runoff and precipitation events are reflected in hydrographs of the wells, but erratic variations in the hydrographs suggested limited surface water influences.

Basin C

Basin C is situated in the southeastern quarter of Section 26 and encompasses an area of approximately 77 acres (Figure 2.4-31). The basin is a natural depression defined by the 5,209 ft msl elevation contour. Earthen dikes were constructed on the northern and western basin boundaries to enhance impound of contaminated wastes overflowing from Basins A and B. Concrete weirs and unlined ditches connect Basins C, D and E.

Topographically the area slopes to the north and west towards Basin F and D. Basin C receives runoff from the east and southeast. Dry grassland surrounds Basin C much of which is devoid of other vegetation. Most of the basin is located north of the northwest-trending bedrock paleochannel. Alluvium beneath the basin is unsaturated except in the northeast and extreme southwest part of the basin in close proximity to the paleochannel.

There are six alluvial monitoring wells in the vicinity of Basin C; two upgradient (35007 and 26085) and four downgradient (26010, 26050, 26005 and 26006). The range and average water table elevation for these wells during 1986 and 1987 are provided in Table 2.4-11. Water-table fluctuations in the wells range from 1.2 to 4.0 ft. The saturated alluvium thickness ranges from 1.2 to 5.4 ft in wells adjacent to the area of unsaturated alluvium, while in Wells 26006 and 35007, situated south of the basin, the thickness of saturated alluvium increases to 12.2 and 13.9 ft, respectively. The groundwater table varies from 21 to 41 ft below the ground surface.

Basin C is mostly dry, but occasionally contains surface water accumulations. In order to determine the possible interactions between surface water and groundwater, groundwater level data from the six monitoring wells were evaluated and compared with precipitation and Basin A inflow data. The groundwater fluctuations do not reflect surface water events. Considering that the depth to the groundwater (20 to 40 ft) and the distance from Basin A, a delayed response to surface water fluctuations would be expected.

Table 2.4-11 1986 and 1987 Water-Level Data for Basin C

Well #	Range of Water Table Elevations ¹	1986-1987 Mean Elevation ¹
35007	5,186.8 to 5,190.8	5,189.5
26085	5,179.6 to 5,181.2	5,180.4
26010	5,162.7 to 5,164.0	5,163.3
26050	5,157.7 to 5,159.4	5,158.1
26005	5,158.6 to 5,161.8	5,159.2
26006	5,160.6 to 5,161.8	5,161.0
Basin C	Bottom elevation	5,192.8

¹ Feet above mean sea level

Source: ESE, 1988.

Basins D and E

Basins D and E are located west of Basin C in the southwest quarter of Section 26. Both basins are natural depressions that have been dammed with earthen dikes on the western boundaries as impoundments for Basin C overflow.

Basin D, defined by the historic high water line at 5,193 ft msl, encompasses approximately 20 acres. Basin E, located west of Basin D, has an estimated areal extent of 29 acres and a perimeter elevation of 5,180 ft msl. The surrounding ground surface slopes from the east to the west. The basins may receive local runoff from surface water catchments extending to the east and southeast. Basin E may also receive runoff from the northeast. Surface runoff, however, rarely occurs due to the high permeability and infiltration capacity of the soils. Basins D and E are currently dry and vegetated. Because both basins generally remain dry they are not considered to be a significant area of surface water/groundwater exchange.

2.4.4.7 Basin F

Basin F is a man-made reservoir located in the north-central portion of Section 26 (Figure 2.4-31). It is located in a natural depression defined by the 5,200 ft msl elevation contour. The approximate areal extent of the basin is 93 acres. Earthen dikes were constructed on the northern and western perimeters to increase the average depth to 10 ft to control surface water runoff. The basin was subsequently lined with asphalt to prevent groundwater contamination. The basin has been removed under an Interim Response Action. Liquids are stored in tanks and lined impoundments and contaminated soils are stored in a lined waste pile. Areas of standing liquid within Basin F were pumped dry in July 1988. A larger body of liquid located in the northern portion of the basin was isolated by dikes from smaller bodies in the west and south. Previous estimates of the total volume of fluid in Basin F were 3 million gallons (October 1986) and 5 million gallons (January 1987) (Wilson, 1987, RIC#88162R03). Tanks and impoundments currently hold about 8 million gallons of fluid removed from this basin. Past liquid level fluctuations are undetermined.

The ground surface east of the basin area slopes to the north-northwest and west of the basin area it slopes to the west. The only inflow into Basin F was direct precipitation, except in 1986 when surface runoff entered the basin.

Monitoring wells in the vicinity of Basin F are concentrated along the basin's northern perimeter, downgradient of the site. Groundwater fluctuations and the average water level for selected wells are provided in Table 2.4-12 for 1986 and 1987. Well locations are shown on Figure 2.4-31. The average groundwater levels across the basin range between 5,163 and 5,145 ft msl and fluctuate between 0.6 and 1.5 ft. The basal alluvium overlying bedrock is saturated, and the upper section underlying between 0.5 and 3.5 ft the basin is dry. The average depth to groundwater in the monitoring wells ranges between 41 ft in Well 26010 and 47 ft in Well 26018. The groundwater table is approximately 30 to 40 ft below the ground surface.

Data from downgradient monitoring wells were compared to assess the possible recharge effect of Basin F liquid on the groundwater. A regression analysis was used to evaluate the relationship between the precipitation and groundwater data from the downgradient wells. The correlation coefficient for these two variables was very low, indicating that leakage from the basin was insufficient to produce an immediate response in the groundwater.

Uvalda Interceptor and Highline Lateral

Uvalda Interceptor collects water draining the off-post residential area south of Sections 7 and 12. The Uvalda Interceptor traverses the eastern side of Section 12 and terminates at the east end of Lower Derby Lake (Figure 2.3-3). Highline Lateral carries water from the Highline Canal to the Uvalda Interceptor crossing from the southeast to the northwest corner of Section 7. The confluence of the Highline Lateral and Uvalda Interceptor is located in the southeast corner of Section 1.

Generally, Uvalda Interceptor flows are continuous, averaging around 25 ac-ft/mo at the north gage and 54 ac-ft/mo as it enters RMA. Highline Lateral flows occur in short infrequent events averaging 145 ac-ft/mo.

There are three wells in the vicinity of the channels: Well 07001 is located within 50 ft of Highline Lateral near the center of Section 7; Well 12001 is located approximately 700 ft directly east of the South Uvalda gaging station; and Well 12002 is approximately 2,600 ft to the northwest of Well 12001.

Table 2.4-12 1986 and 1987 Water-Level Data for Basin F

Well #	Range of Water Table Elevations ¹	1986-1987 Mean Elevation ¹
26010	5162 to 5164.0	5163.3
26009	5145.0 to 5145.7	5145.4
26016	5146.3 to 5147.5	5146.5
26017	5146.6 to 5147.2	5146.8
26018	5145.8 to 5147.3	5146.3
26020	5148.3 to 5149.5	5149.1

¹ Feet above mean sea level

Source: ESE, 1988.

Figure 2.4-32 displays well hydrographs and the surface elevations for Uvalda Interceptor. Water levels in Well 07001 average 11.6 ft above the South Uvalda water level. South Uvalda water surface elevations exceed those of the upgradient Well 12001 by 0.6 ft and of the downgradient well by 20.2 ft. Uvalda water surface is above the groundwater table in this area and may recharge the groundwater. Both Highline Lateral and Uvalda Interceptor cross eolian deposits, and traverse a branch of the Irondale paleochannel.

Water levels in Wells 12002 and 07001 have greater fluctuations than in Well 12001 located next to Uvalda Interceptor. The cause of these fluctuations is unknown, but Uvalda Interceptor appears to be influencing fluctuations observed in Well 12001. A consistent seepage loss rate from Uvalda Interceptor could have a dampening effect upon adjacent water-level fluctuations. Well fluctuations in Well 07001 are the most extreme, but are poorly correlated with Highline Lateral flows.

Water balance calculations indicate that Uvalda Interceptor losses average approximately 30 ac-ft/mo. Roughly 40 percent of the Uvalda Interceptor inflow is recharged to the groundwater. Since periods when North Uvalda flows exceeded South Uvalda flows were attributable to potential evaluation errors, they were not included in recharge rate estimates. Assuming an equal recharge rate, Highline Lateral recharge averaged 75 ac-ft/mo for FY86 and FY87.

2.4.4.9 Sewage Treatment Plant

The Sewage Treatment Plant is located near the center of Section 24. The plant processes a low but consistent volume of influent averaging 1 ac-ft/mo and ranging between 0.3 and 1.8 ac-ft/mo. Aldrin, dieldrin, DBCP, chloroform and other contaminants have been detected in the plant effluent. The presence of these compounds may be a result from improper disposal of contaminants in sanitary sewer drains or inflow into deteriorated sewer lines passing through contaminated areas.

Effluent from the plant exits via a 4 inch PVC pipe into a lined ditch that discharges into First Creek. The ditch is lined for about the first 40 ft of the total 1,600 ft length. Consequently, effluent may not reach First Creek due to ditch losses.

For this analysis, wells up and downgradient of the lined channel (24098 and 24103) were compared with wells up and downgradient of the unlined section (24003 and 24117) (Figure 2.4-33).

As a preliminary indicator, regression analyses were performed using the upgradient well water levels to predict the downgradient well water levels for both the lined and unlined ditch segments. The results of these analyses revealed the plant discharges did not have an impact on groundwater levels downgradient of the effluent ditch.

Water quality data for the well downgradient of the unlined ditch segment and the plant effluent were reviewed. Carbon tetrachloride and DBCP were detected in the well samples. Carbon tetrachloride was detected in 3 of 3 well samples with an average concentration of 14.63 ug/l. This contaminant was also detected in 2 of 5 plant effluent samples at average concentration of 7.95 ug/l. DBCP was detected once in both sources, however the groundwater had a higher concentration of 0.563 ug/l and the plant had a lower concentration of 0.150 ug/l. Aldrin and dieldrin were detected in plant effluent in 5 of 5 and 4 of 5 samples, respectively, but were not detected in the well samples. Plant effluent does not appear to act as a significant source of groundwater recharge to the alluvial aquifer.

2.4.4.10 First Creek and North Bog

First Creek enters RMA at its southeast corner, traverses the Arsenal in a northwesterly direction and exits near the center of the north boundary. Off-post flow becomes westerly along the north boundary where it eventually discharges into the O'Brian Canal. The North Bog is located on-post at the north boundary in Section 24. Over the last five years North Bog has received overflow from the North Boundary Containment System recharge wells.

There are numerous wells along First Creek with the greatest density around the North Boundary Containment System, and fewer in the southeast corner of the site. A north-to-south cross-section, illustrating the groundwater elevation in relation to the stream bed elevation, is given in Figure 2.4-34. The cross-section was constructed using stream bed elevations at road crossings and corresponding water table elevations from a Fourth Quarter FY87 water-table elevation contour map.

The groundwater level is below the elevation of the bottom of the stream channel at Sixth and Seventh Avenues and the north boundary coincides with the locations where First Creek is superimposed on the First Creek paleochannel. The exception to this is at 8th Avenue, where the stream bed is incised.

None of the extrapolated water table elevations exceed the channel bottom elevations by more than a foot. Therefore, for flows exceeding 1 ft in depth, recharge to the groundwater would occur for the entire length of First Creek on-post.

Water balance calculations for First Creek show that the south gage upstream averages approximately 990 ac-ft/yr while the north gage downstream averages 690 ac-ft/yr. This indicates that 310 ac-ft/yr was lost between the two gages for WY86 and WY87, or about 30 percent of the inflow. The most substantial losses occur in late summer as the discharges at the South First Creek gage are increasing from mid-summer low flows. A large amount of this water is required to recharge the aquifer before the north First Creek gage is impacted. This is shown in Figure 2.4-35 which compares flows at the two gages.

Generally, groundwater levels increase throughout the fall and winter to a peak in May and then rapidly decline to a low in August.

First Creek baseflow is highest in March and lowest in August and closely follow net evaporation fluctuations.

Off-post downstream groundwater discharges into First Creek has been observed. This is of concern because the discharge area is hydraulically downgradient from contaminated groundwater. Groundwater discharge into First Creek was documented by comparing stream-bed elevations to water levels from wells located near First Creek. Although the number of wells is limited, these data indicate that groundwater levels exceed stream bed elevations by several feet in some areas. These data also show that areas of potential groundwater discharge are present in both Sections 13 and 14 north of RMA. Figure 2.3-36 shows the elevations of the First Creek stream bottom and groundwater along First Creek from the RMA north boundary to Highway 2.

Stream bottom and water-surface elevations were measured in a survey of the First Creek channel conducted August 10 through 14, 1987. During the survey, no flow was observed at the North Boundary gage, in the overflow pipe leading from the impoundment in Section 14, or at the Highway 2 gage. Since flow was not detected at the Highway 2 gage for a week prior to the survey, and for over a month at the North Boundary gage, it was assumed that standing water levels in First Creek represented groundwater levels. Groundwater elevations were extrapolated from the Fourth Quarter FY87 groundwater elevation map. Despite its limitations, Figure 2.4-35 provides a good illustration of the relative position of the groundwater in relation to the stream bed elevation in Sections 13 and 14 off-post. Off-post groundwater elevations exceed the channel bottom elevation from north of the north boundary to Peoria Street, and downstream of the Farm Pond at Highway 2 suggesting groundwater discharge. Along stream segments where the groundwater elevations are below the stream bed, First Creek is a potential source of groundwater recharge.

Figure 2.4-37 shows the difference in monthly total flows measured within First Creek at the RMA north boundary and at the Highway 2 gage. Gage locations are identified in Figure 2.3-2. Before and after the primary flow season, the downstream gage records flow while the upstream gage remains dry and groundwater appears to be the source of this flow. Highway 2 gage records flow that begins later and ends earlier than the North Boundary gage, however, it records a larger total discharge. This indicates that channel losses exceed groundwater base flow. The capacity of the farm pond only accounts for approximately 10 ac-ft of storage, and would therefore not alter the conclusions.

Gains and losses for First Creek are illustrated in Figure 2.4-38. This figure is a plot illustrating Highway 2 gage flow (plotted along the X-axis) and the net gain or loss (Y-axis). Net gain in the flow from the upstream to the downstream gage is plotted above the zero line. Water loss is plotted below the zero line discharge. For lower stream at the Highway 2 gage, groundwater baseflow exceeds stream loss resulting in groundwater discharge. For higher flows at the Highway 2 gage, stream loss exceed groundwater inflows resulting in groundwater recharge (Figure 2.4-38). It is not known if an increase in surface water elevations during higher flows prevents groundwater baseflow. Alternatively, groundwater baseflow could occur in some segments and groundwater recharge in others. As shown in Figure 2.4-38, it appears net losses (groundwater recharge) equal net baseflow when stream discharge is 3 ac-ft/day or less at the

Highway 2 gage. Inspection of Figure 2.4-37 indicates that during periods of low First Creek discharge groundwater baseflow into First Creek is approximately 0.06 cfs.

A large discharge in First Creek can inhibit the baseflow of contaminated groundwater into the stream channel; however large discharges do not occur frequently enough to influence long term conditions. Figure 2.4-39 illustrates the number of days on which flows of different magnitudes have occurred between July 1986 and August 1987. Assuming a stream discharge of 3 ac-ft/day balances baseflow and recharge, an analysis of Figure 2.4-39 suggests that groundwater baseflow exceeds channel losses on 295 days out of 327 days of monitoring. Even though the total flow volume at North Boundary gage exceeds that at the downstream gage, large surface discharges do not occur frequently enough to provide an effective means of inhibiting groundwater baseflow to First Creek.

Surface water/groundwater quality data also support the occurrence of groundwater discharging into the off-post segments of First Creek. Contaminants found in samples collected from First Creek at the Highway 2 station occur in groundwater samples collected from wells north of the RMA north boundary. Concentrations of organic parameters (diisopropylmethyl phosphonate, 1,2-dichloroethane, dicyclopentadiene, chlorophenylmethyl sulfone, and 1,4-Dithiane) and inorganic parameters (chloride, fluoride, and sulfate) are higher in samples collected from the Highway 2 station than at the North Boundary station. These parameters are present in the groundwater along the off-post stream segments, at higher average concentrations, than in the off-post surface water samples collected along First Creek. Higher concentrations were found in samples from the Highway 2 station. This helps substantiate the hypothesis that groundwater is infiltrating to First Creek off-post.

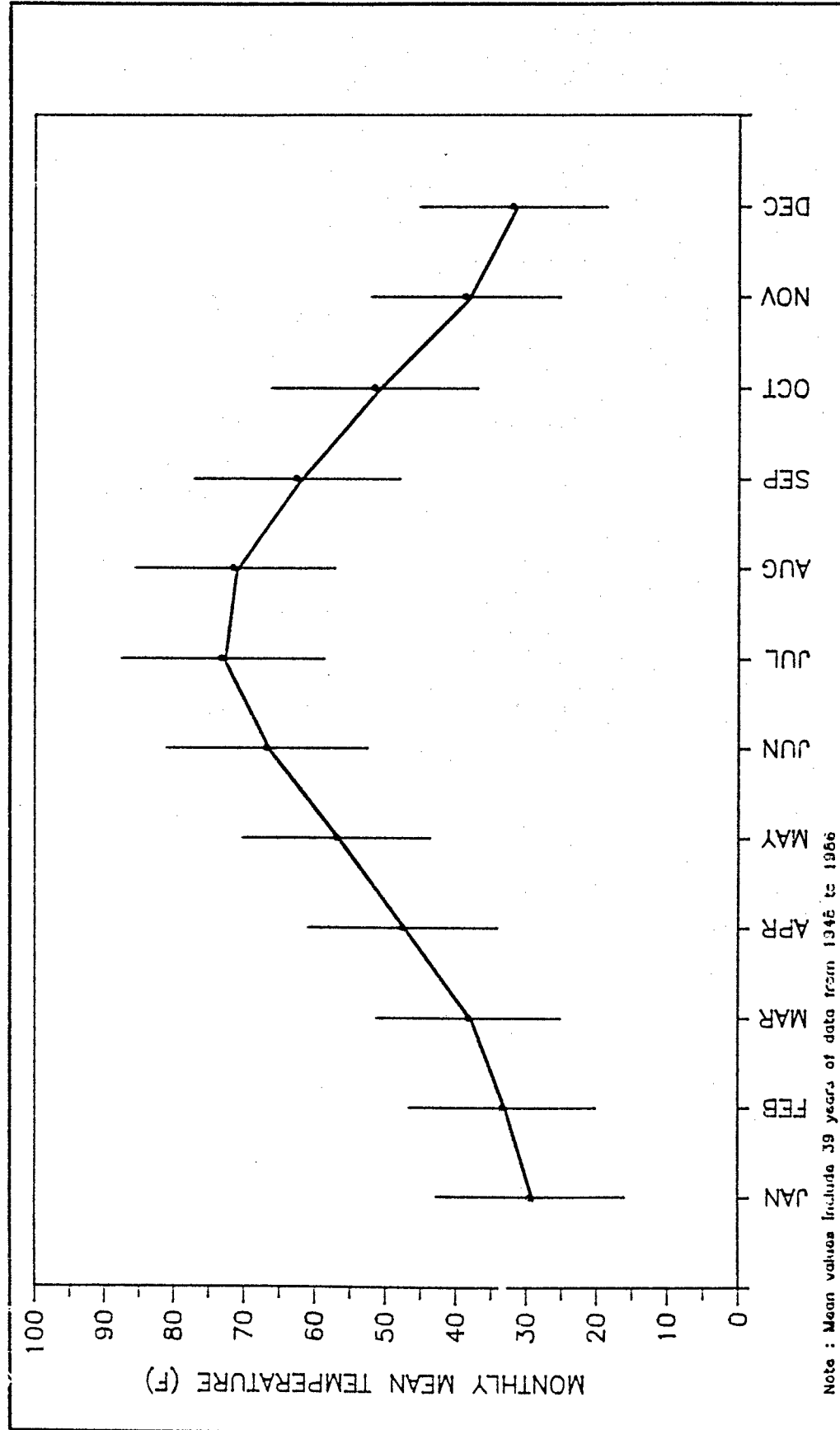
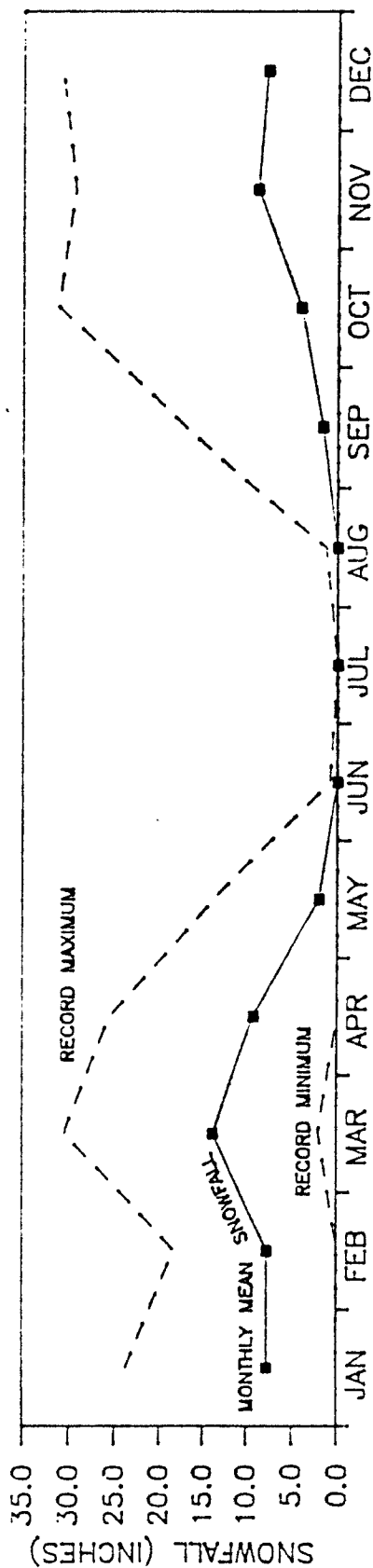
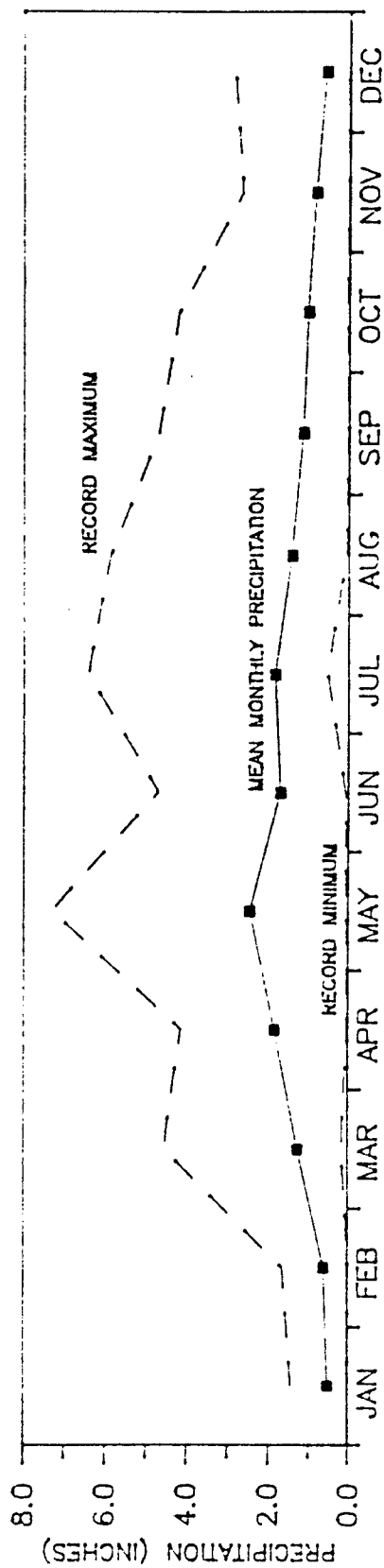


Figure 2.1-1

Prepared for:
U.S. Army Program Manager's Office

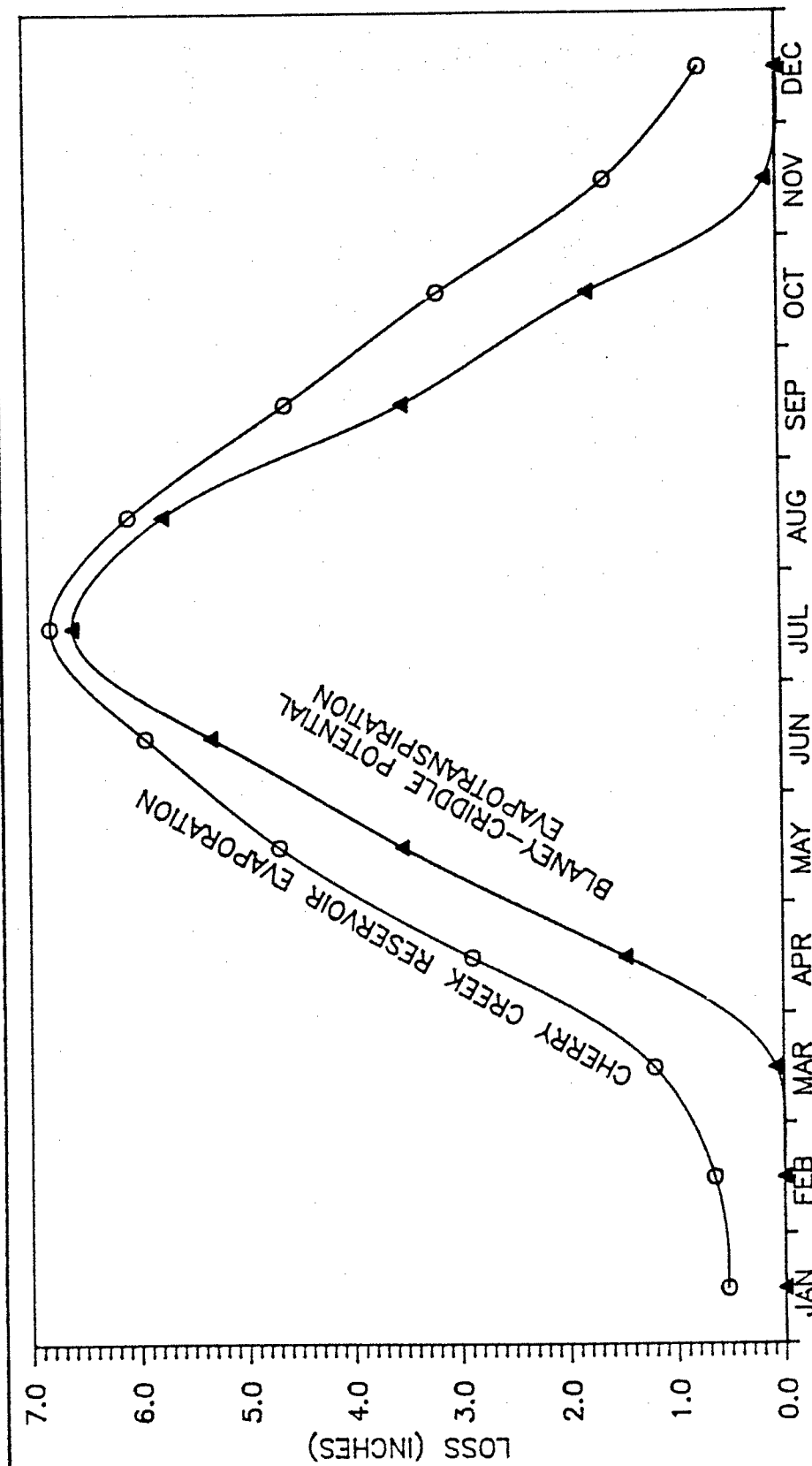


Note: Mean values include 39 years of data from 1948 to 1986

Figure 2.1-2

MONTHLY TOTAL SNOWFALL AND PRECIPITATION FOR

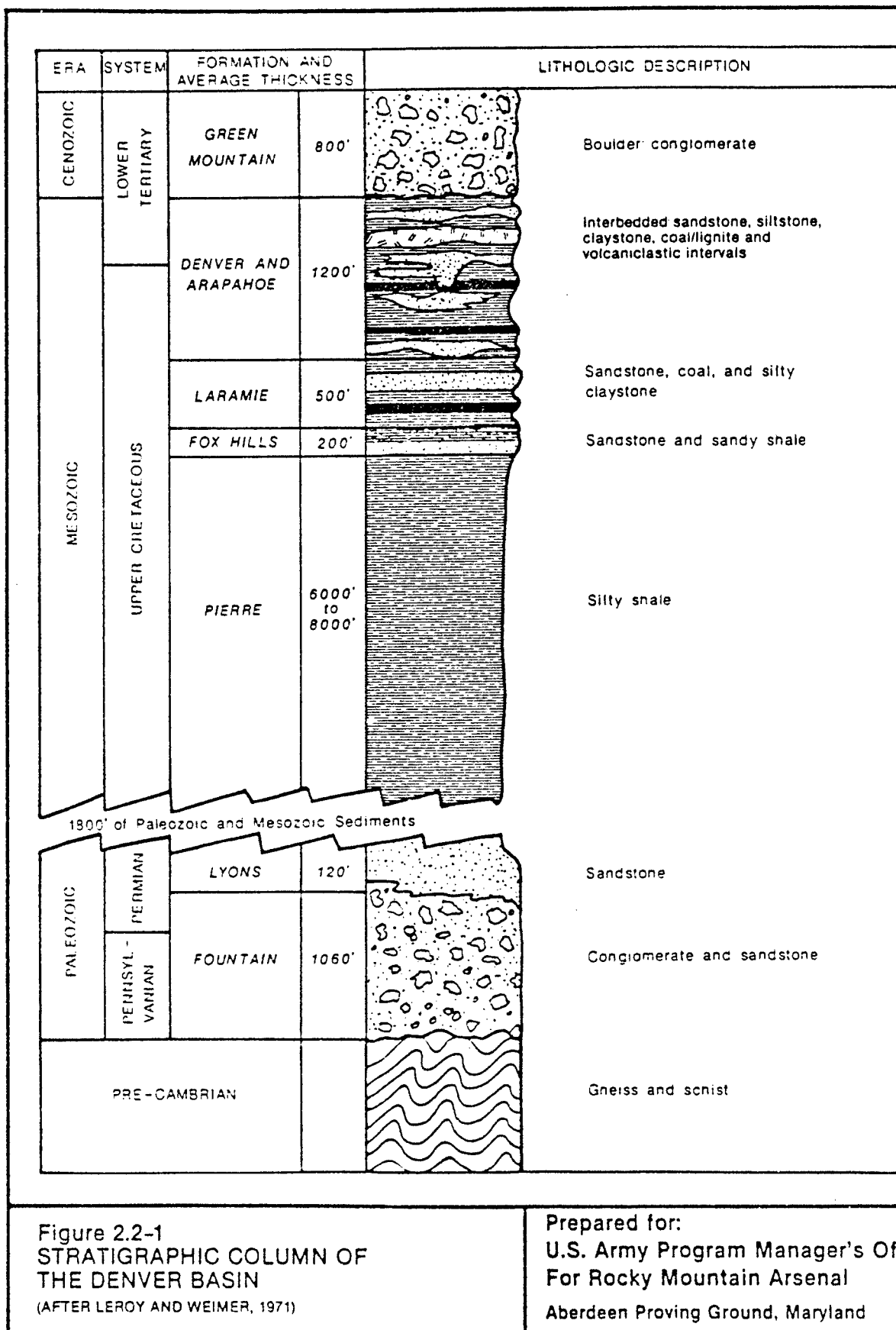
Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal

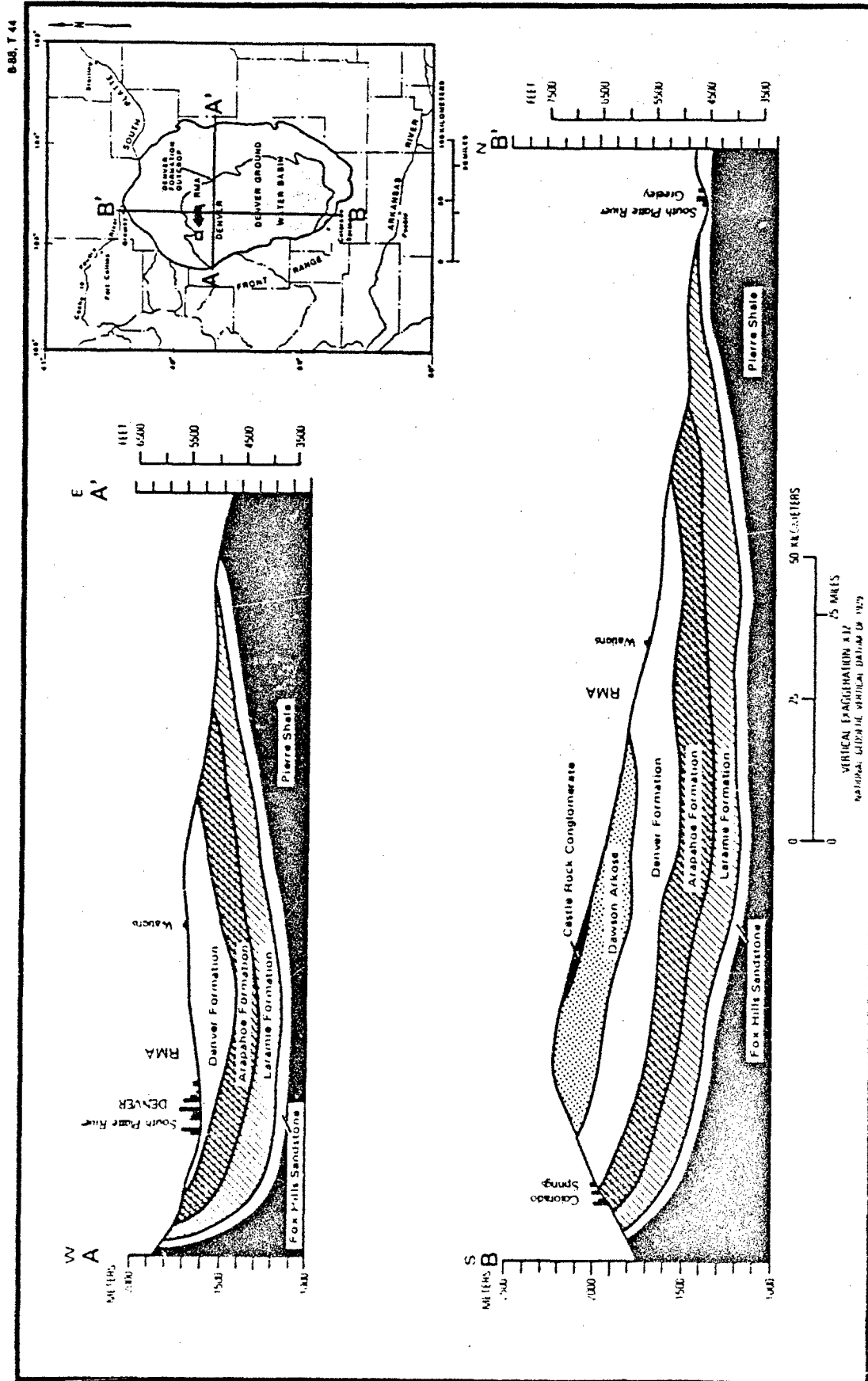


Note : Mean values include 39 years of data

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal

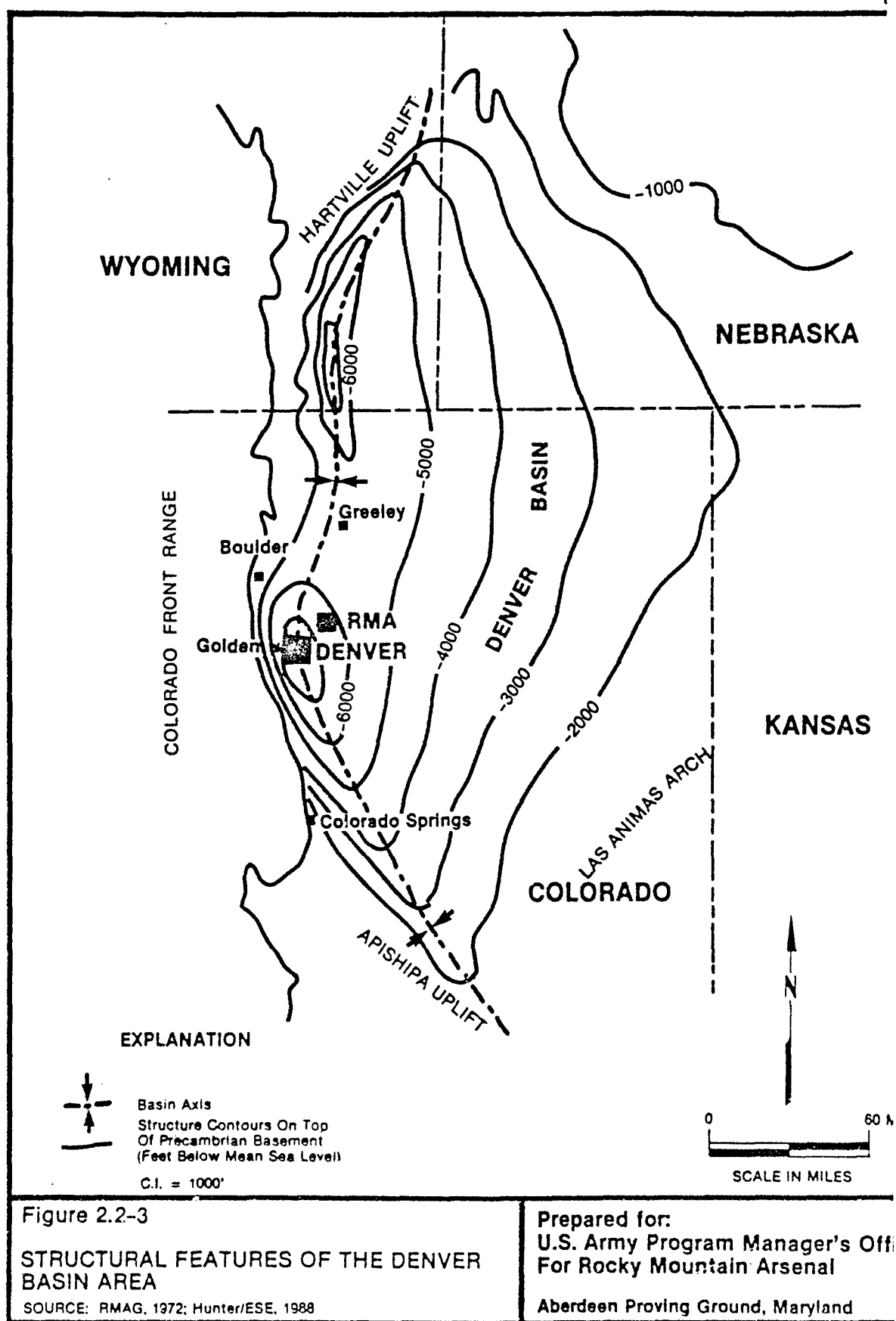
Figure 2.1-3
ESTIMATED BLANEY-CRIDDLE EVAPOTRANSPIRATION AND CHERRY


















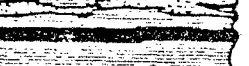




Prepared for:
U.S. Army Program Manager's Office

Figure 2.2-2
UPPER STRATIGRAPHIC SECTIONS OF THE DENVER BASIN



SYSTEM	ZONE & THICKNESS		LITHOLOGIC DESCRIPTION	
QUATERNARY	Alluvium	0-130'		Gravels, silty sands, sandy silts, and clays; laterally variable
CRETACEOUS - TERTIARY DENVER FORMATION	B	0-25' (0-15')		B Sandstone and claystone
	Volcanic-clastic	0-50'		Volcaniclastic material and laterally equivalent claystone and sandstone
	A	0-75'		<div> <div> AU (0-13') AM (0-20') AL (0-20') </div> <div> AS (0-46') </div> </div> Sandstone, claystone, and lignite
	Lignite A	0-11'		
	IU	0-40' (0-36')		
	Lignite B	0-12'		
	1	0-60' (0-54')		
	Lignite C	0-13'		
	2	0-55' (0-41')		
	Lignite D	0-13'		
	3	0-45' (0-33')		
	4	0-50' (0-36')		
	5	0-25' (0-19')		
	6	0-30' (0-23')		
	7	0-30' (0-20')		
	8	0-40' (0-27')		
	9	0-20' (0-6')		

NOTE: Not to Scale. Net Sandstone Thickness Shown in Parentheses.

Thickness for Zone 5 through Zone 9 based on limited data.

Figure 2.2-4

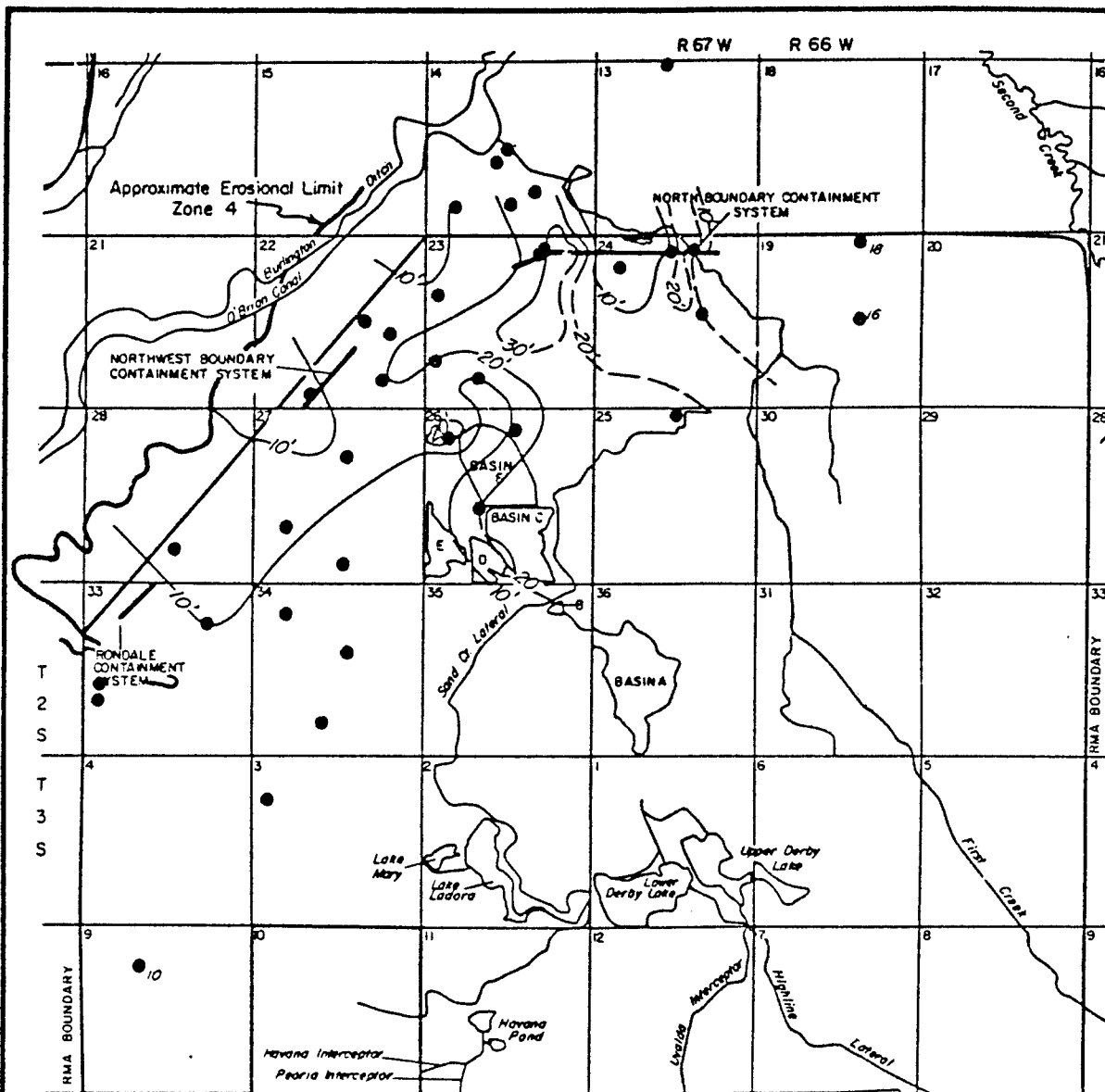
RMA STRATIGRAPHIC COLUMN

SOURCE: HLA, Hunter/ESE, 1988

Prepared for:

U.S. Army Program Manager's Office
For Rocky Mountain Arsenal

Aberdeen Proving Ground, Maryland



EXPLANATION

- Control Point
- 10' Isolated Control Point With Net Sandstone Thickness Greater Than 10 Feet
- 10' — Line Of Equal Thickness Of Sandstone, Dashed Where Inferred
- Contour Interval Equals 10 Feet

Note:

Net Sandstone Thickness Obtained By Summing Thickness Of Strata Described As Sandstone, Silty Sandstone, Shaly Sandstone, Silty Siltstone, Or Siltstone.

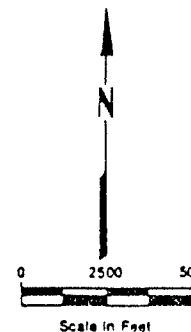
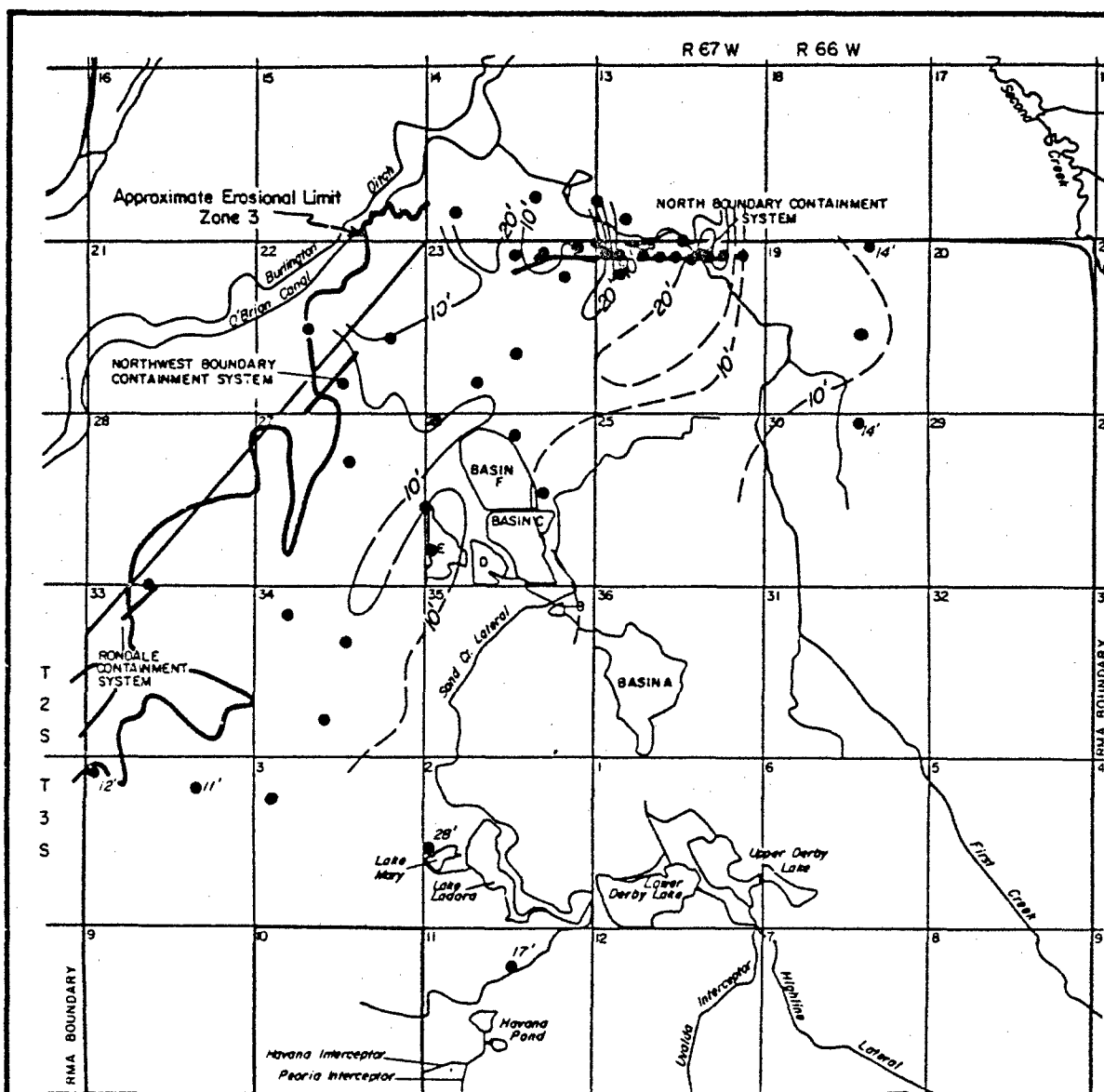


Figure 2.2-5
THICKNESS OF SANDSTONE IN
DENVER ZONE 4

SOURCE: Hunter/ESE, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland



EXPLANATION

- Control Point
- 12' Isolated Control Point With Net Sandstone Thickness Greater Than 10 Feet
- 10' — Line Of Equal Thickness Of Sandstone, Dashed Where Inferred
- Contour Interval Equals 10 Feet

Note:

Net Sandstone Thickness Obtained By Summing Thickness Of Strata Described As Sandstone, Silty Sandstone, Shaly Sandstone, Silty Siltstone, Or Siltstone.



Figure 2.2-6
THICKNESS OF SANDSTONE IN
DENVER ZONE 3

SOURCE: Hunter/ESE, 1988

Prepared for:
U.S. Army Program Manager's Off
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland

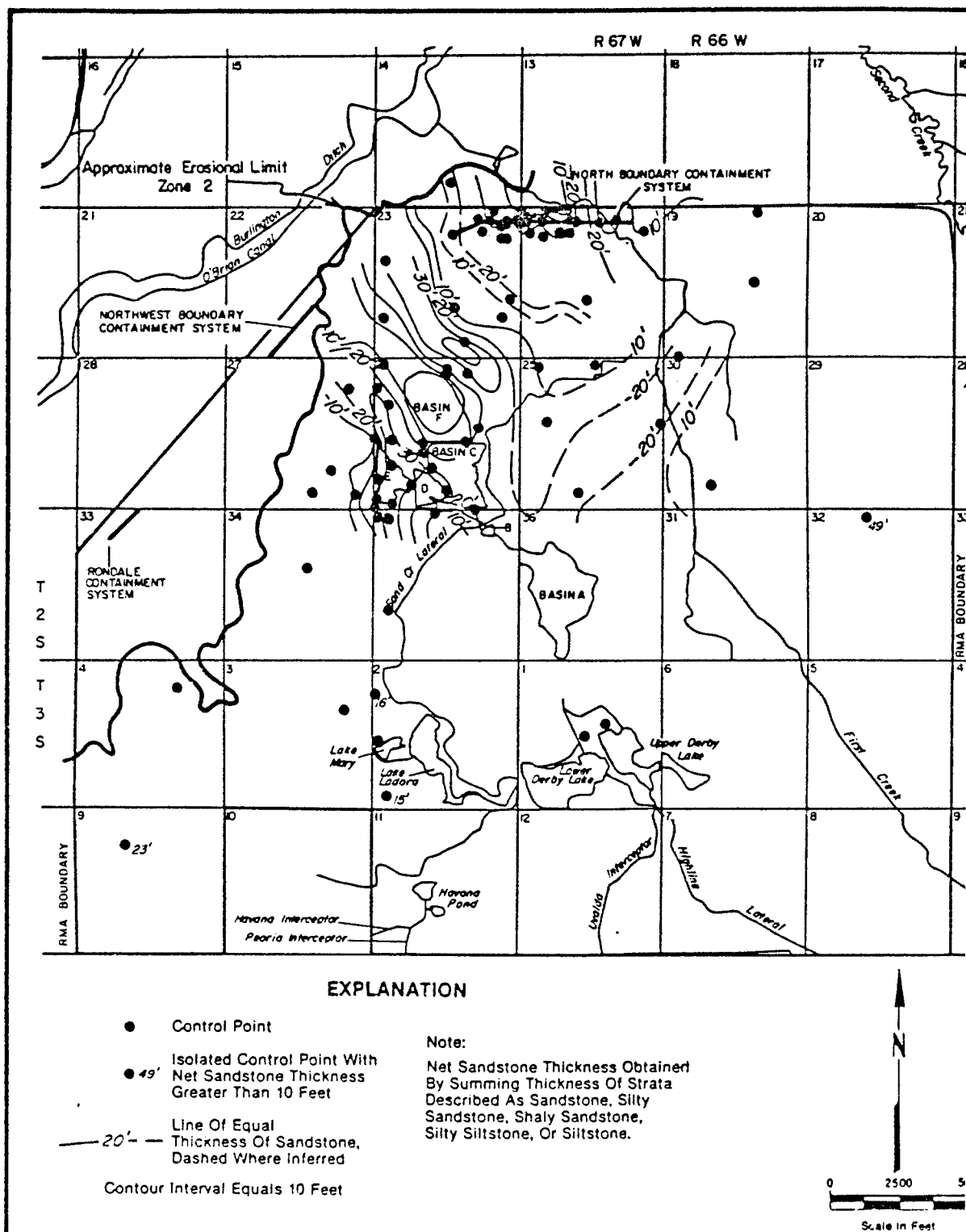
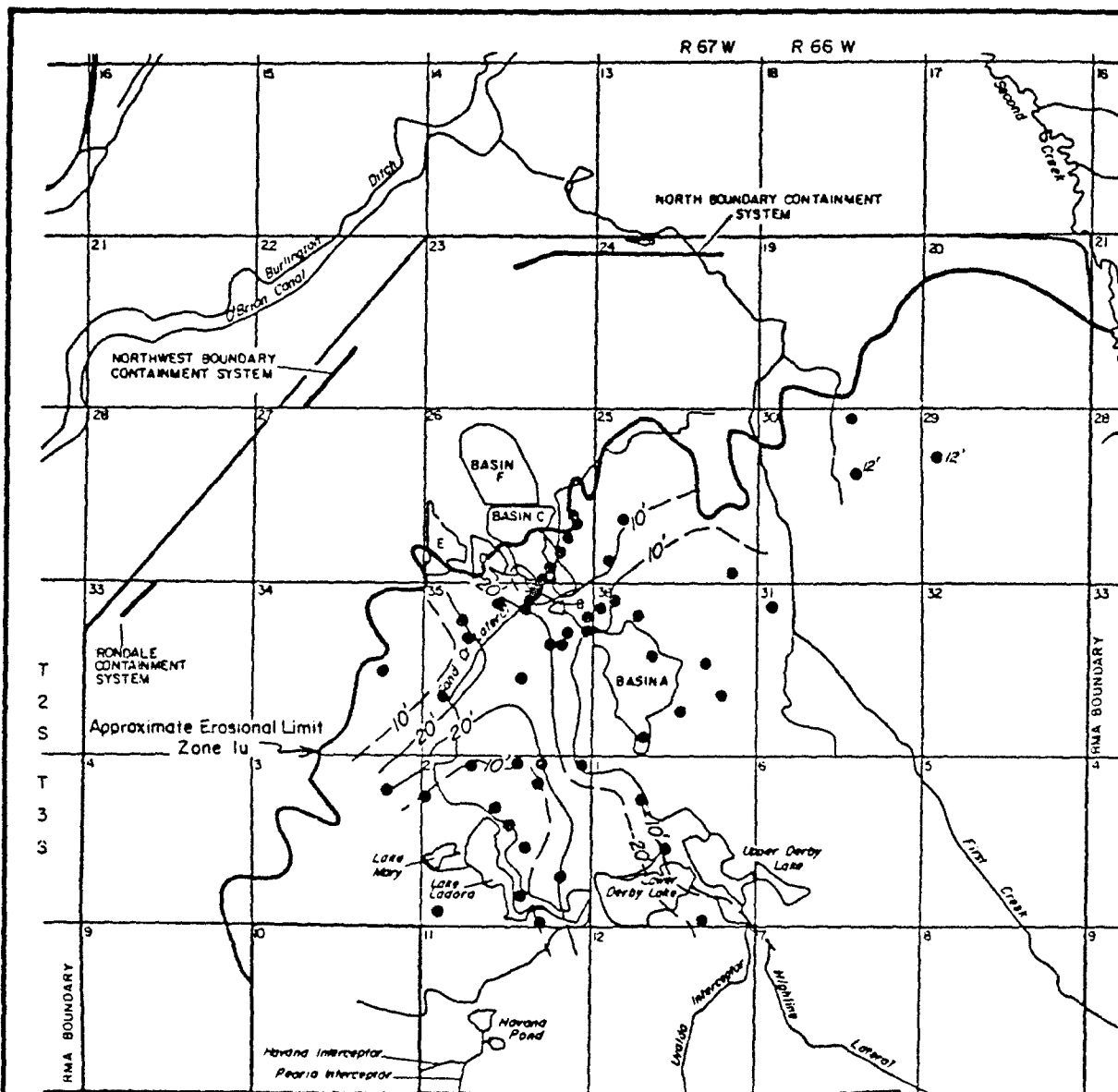


Figure 2.2-7
 THICKNESS OF SANDSTONE IN
 DENVER ZONE 2

SOURCE: Hunter:ESE, 1988

Prepared for:
 U.S. Army Program Manager's Office
 For Rocky Mountain Arsenal
 Aberdeen Proving Ground, Maryland



EXPLANATION

- Control Point
- 12' Isolated Control Point With Net Sandstone Thickness Greater Than 10 Feet
- 20' — Line Of Equal Thickness Of Sandstone, Dashed Where Inferred

Note:

Net Sandstone Thickness Obtained By Summing Thickness Of Strata Described As Sandstone, Silty Sandstone, Shaly Sandstone, Silty Siltstone, Or Siltstone.

Contour Interval Equals 10 Feet



Figure 2.2-9
THICKNESS OF SANDSTONE IN
DENVER ZONE 1U

SOURCE: Hunter/ESE, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland

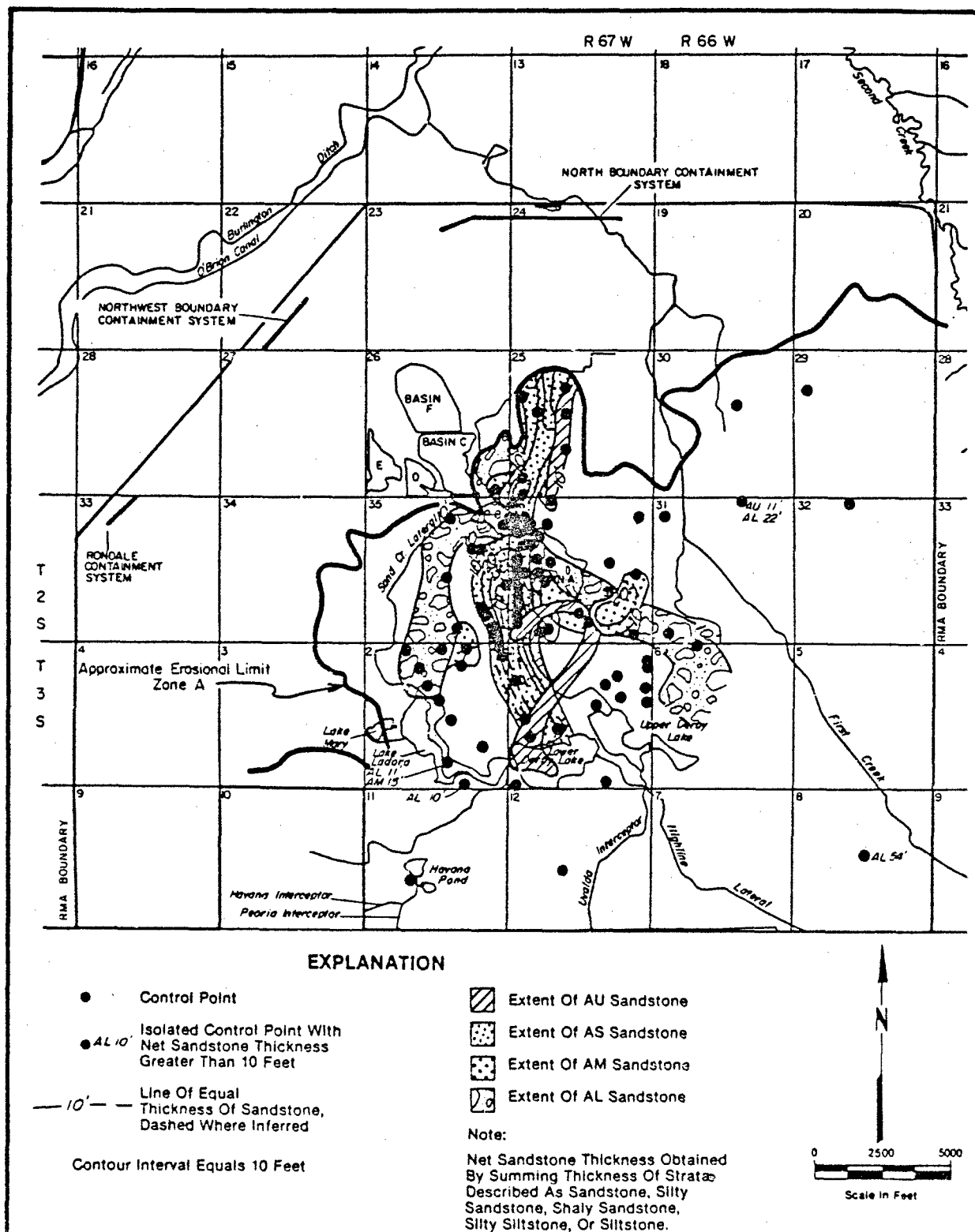
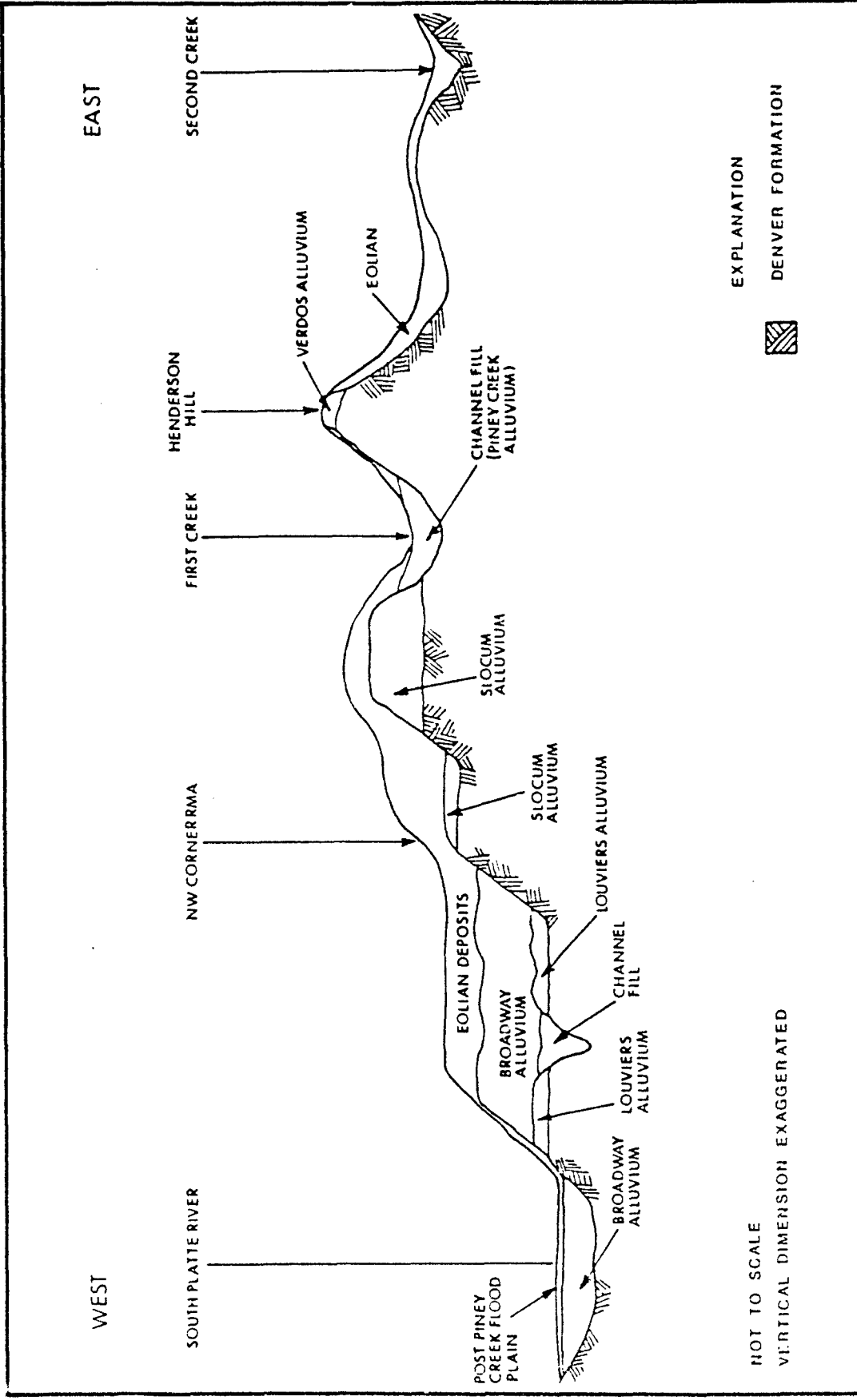


Figure 2.2-10
THICKNESS OF SANDSTONE IN DENVER
ZONE A EMPHASIZING AL, AM, AS, AND
AU SANDSTONE TRENDS
SOURCE: Hunter/ESE, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland



Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal

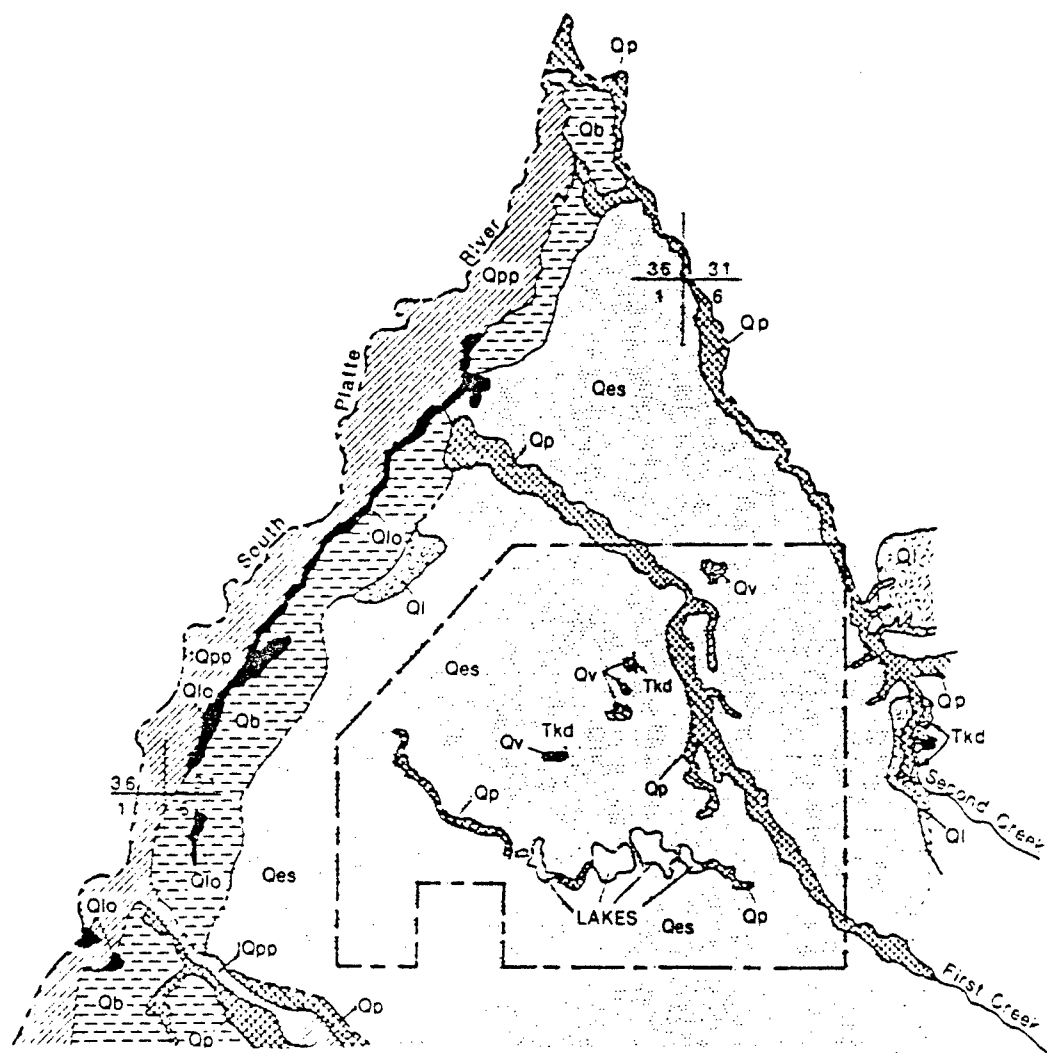
Figure 2.2-11
GENERALIZED EAST-WEST CROSS SECTION FROM THE
SOUTH PLATTE RIVER TO THE NORTHEAST CORNER OF
RMA

ERA	PERIOD	EPOCH	AGE	FORMATION
CENOZOIC	QUATERNARY	HOLOCENE		Post Piney Creek
				Piney Creek
				Eolian
		PLEISTOCENE	Wisconsin	Loess
				Broadway
				Louviers
			Illinoian	Slocum
			Kansan	Verdos

NOT TO SCALE

Figure 2.2-12
QUATERNARY COLUMNAR SECTION
SOURCE: Modified From MKE (1988)

Prepared for:
U.S. Army Program Manager's
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland



EXPLANATION

	Qpp	Post Piney Creek Alluvium (Quaternary)
	Qp	Piney Creek Alluvium (Quaternary)
	Qes	Eolian Sand (Quaternary)
	Ql	Loess (Quaternary)
	Qb	Broadway Alluvium (Quaternary)
	Qlo	Louviers Alluvium (Quaternary)
	Qv	Verdos Alluvium (Quaternary)
	Tkd	Denver Formation (Upper Cretaceous & Tertiary)

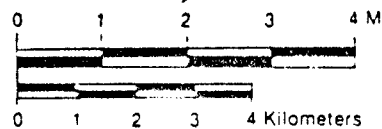


Figure 2.2-13
GEOLOGIC MAP OF ROCKY MOUNTAIN
ARSENAL AREA

SOURCE: LINDVALL (1980, 1983)

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland

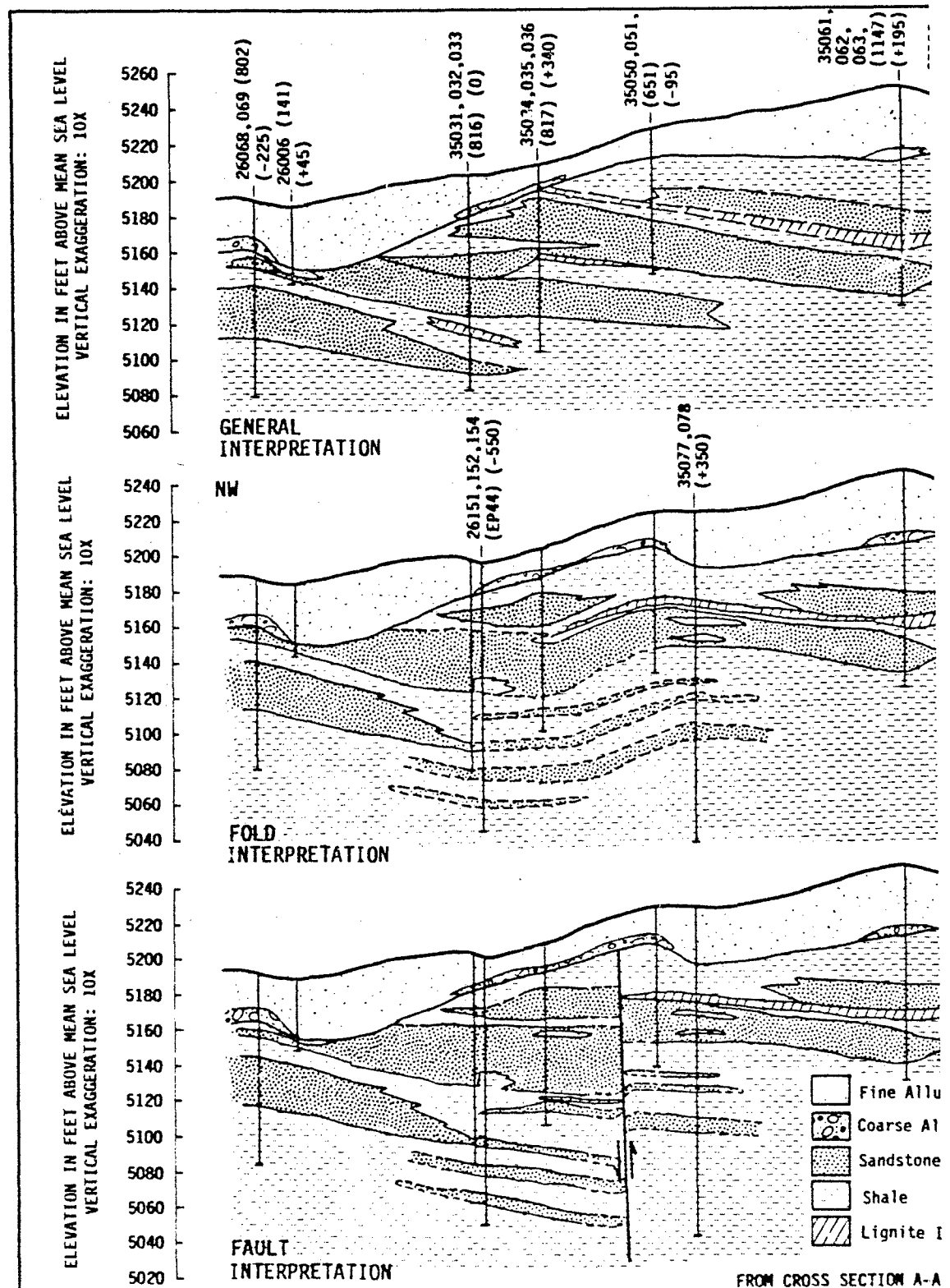


Figure 2.2-14

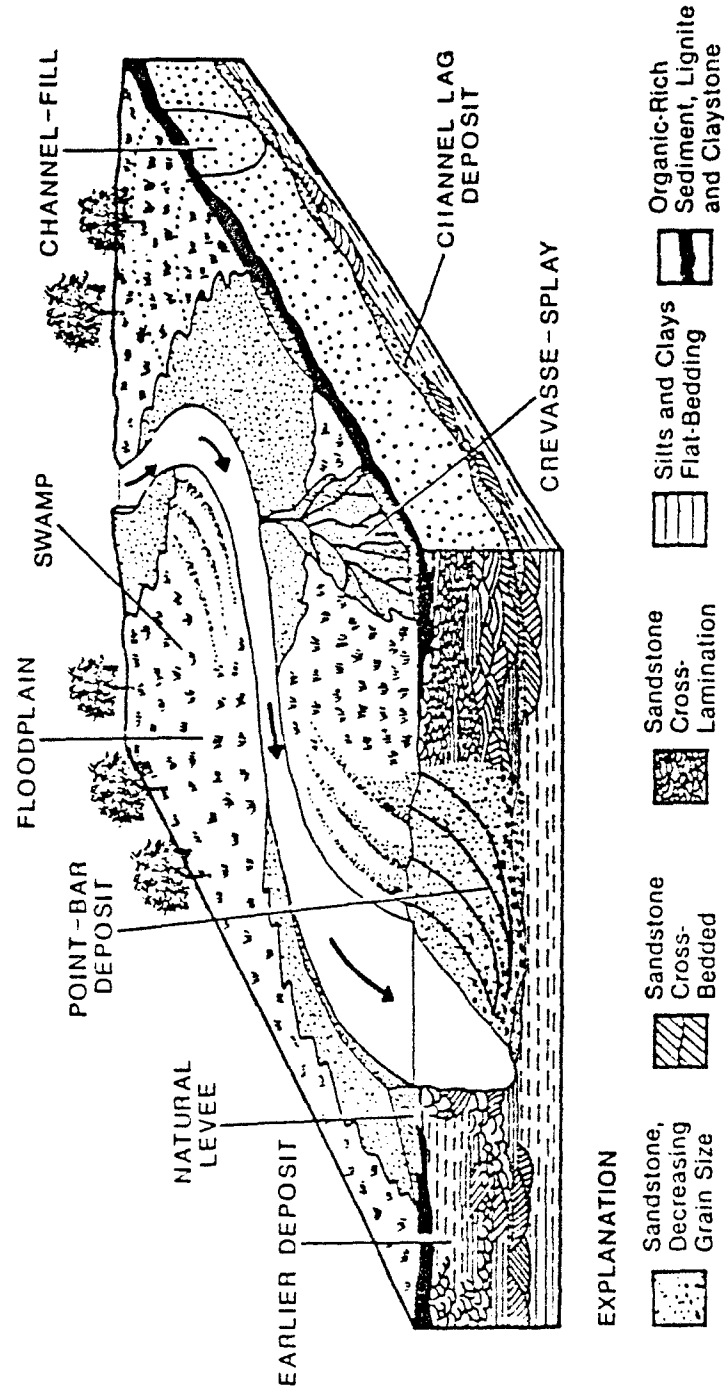
GEOLOGICAL INTERPRETATIONS FOR PART
OF CROSS SECTION A-A'

SOURCE: R L STOLLAR & ASSOCIATES, INC., 1988

Prepared for:

U.S. Army Program Manager's Office
For Rocky Mountain Arsenal

Aberdeen Proving Ground, Maryland



Modified from Allen (1965)

Figure 2.2-15

Prepared for:

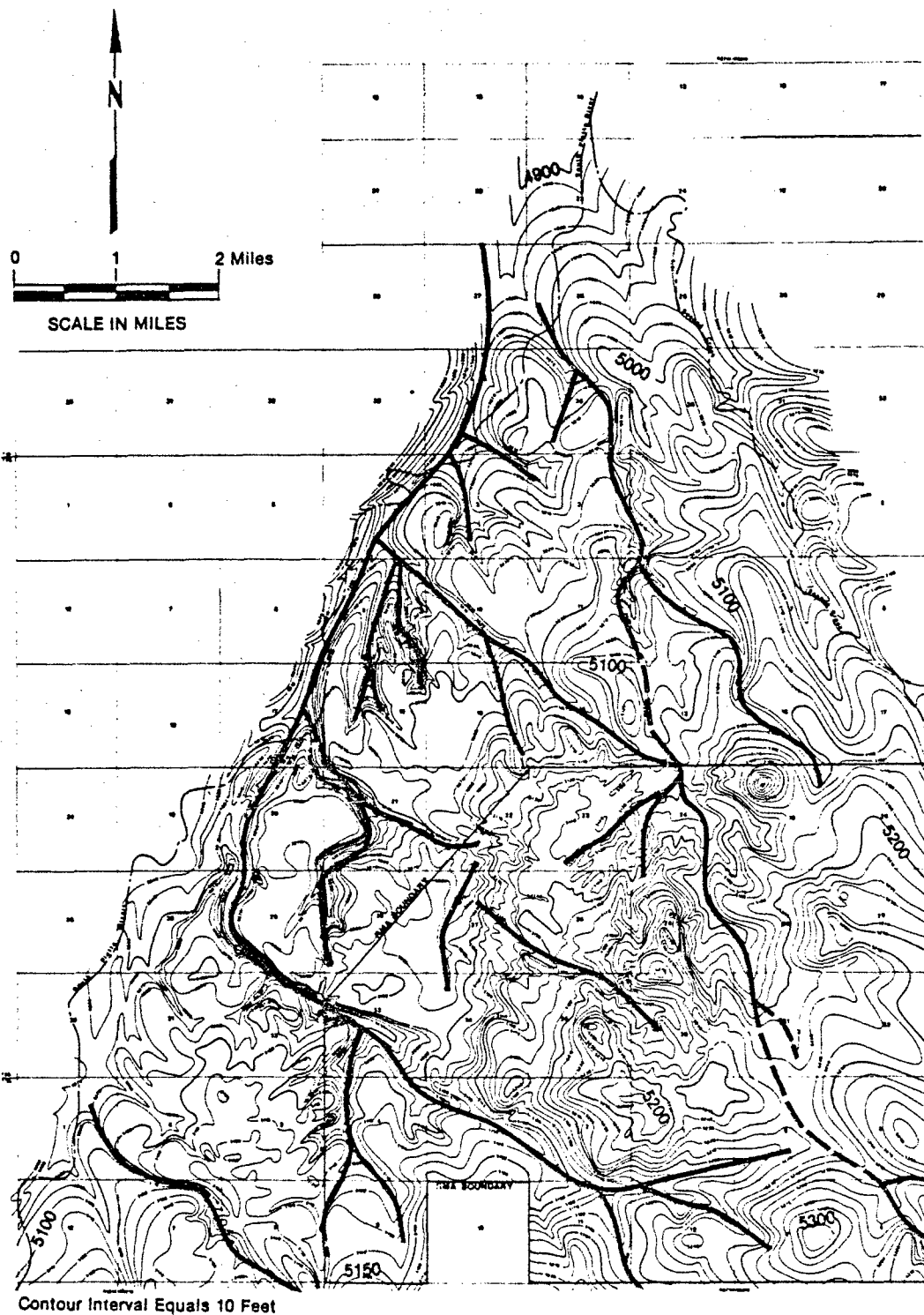


Figure 2.2-16

**BEDROCK SURFACE AT RMA AND
PROMINENT PALEOCHANNELS**

SOURCE: Hunter/ESE, 1988

Prepared for:
U.S. Army Program Manager's C
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland

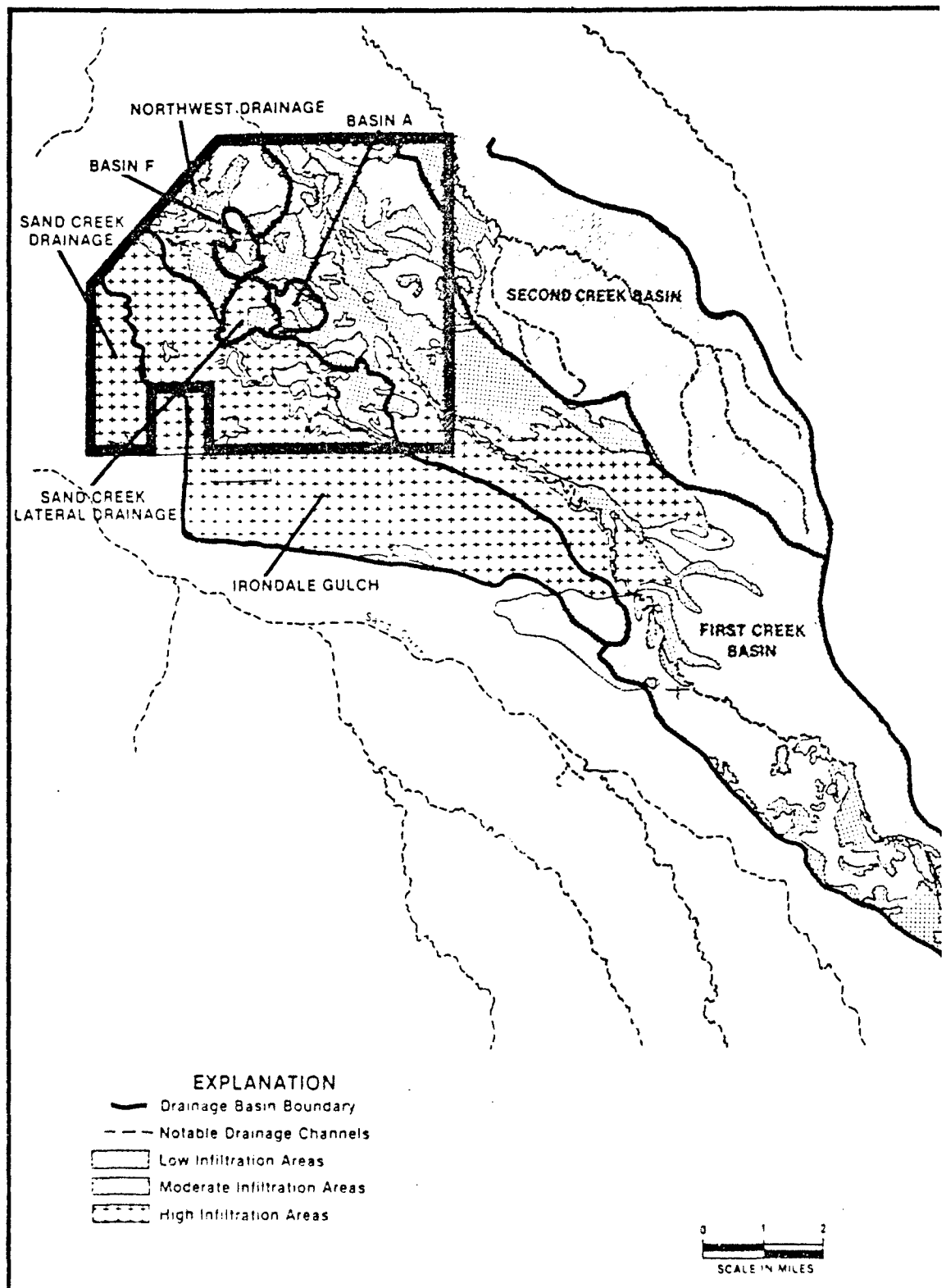
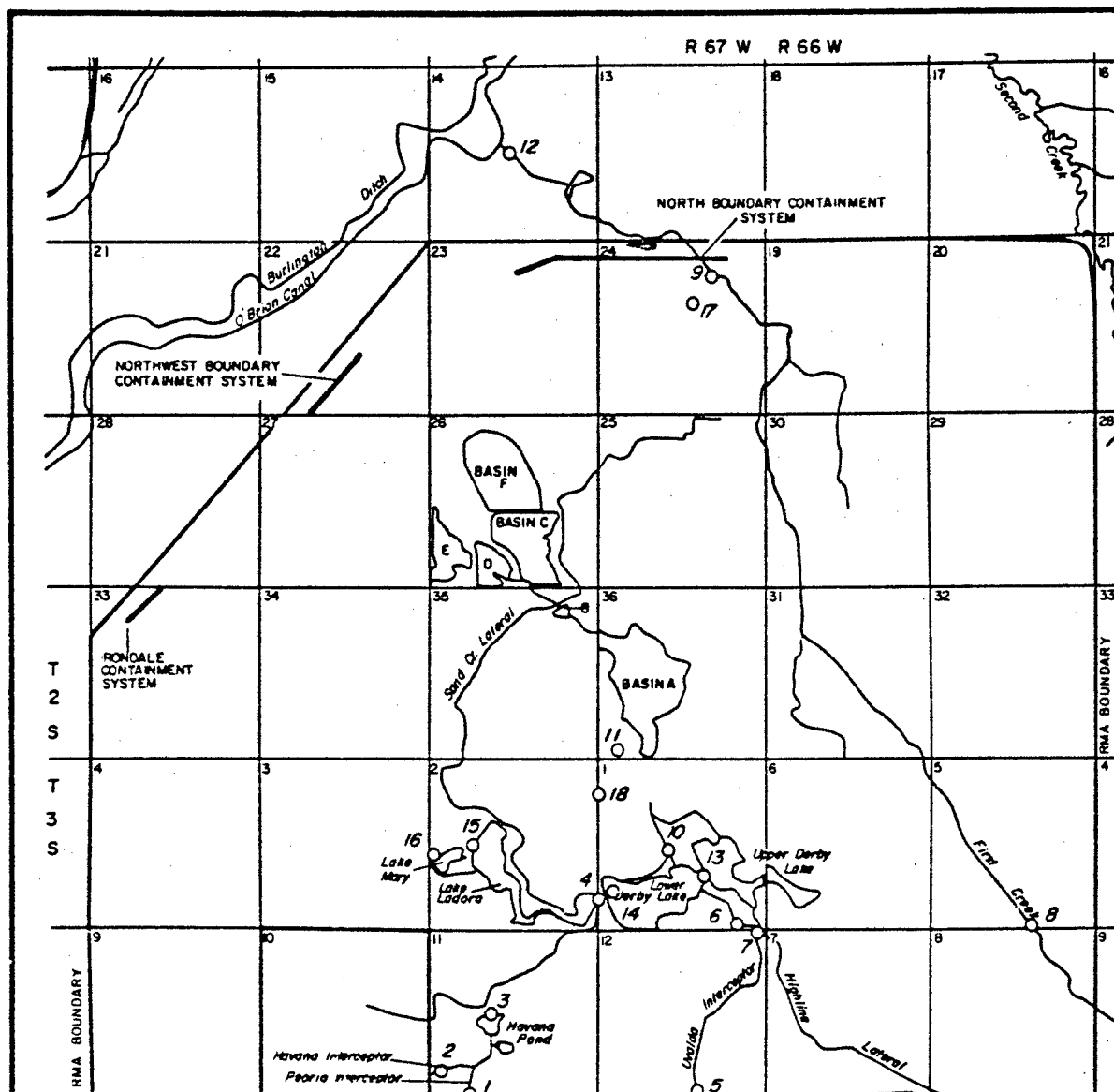


Figure 2.3-1

**INFILTRATION RATES ASSOCIATED WITH
RMA DRAINAGE BASINS**

SOURCE: Hunter/ESE, 1988

Prepared for:
U.S. Army Program Manager's C
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland



EXPLANATION

- | | |
|-----------------------------|--|
| 1. Peoria Interceptor | 11. Basin A |
| 2. Havana Interceptor | 12. First Creek @ Highway 2 |
| 3. Havana Pond | 13. Upper Derby Lake |
| 4. Ladora Weir | 14. Lower Derby Lake |
| 5. South Uvalda Interceptor | 15. Ladora Lake @ Ladora Pump House Gage |
| 6. North Uvalda Interceptor | 16. Lake Mary |
| 7. Highline Lateral | 17. Sewage Treatment Plant @ North RMA Rain Gage |
| 8. South First Creek | 18. South RMA Rain Gage |
| 9. North First Creek | 19. Included But Falls Off The Map: |
| 10. South Plants Ditch | U.S. Weather Service Rain Gage, Section |
| | 20, T3S - R67W |

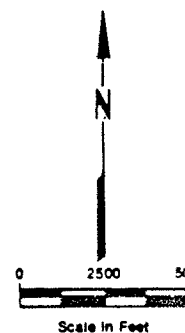


Figure 2.3-2

SURFACE WATER MONITORING SITE LOCATIONS

SOURCE: Hunter/ESE, 1988

Prepared for:

U.S. Army Program Manager's Office
For Rocky Mountain Arsenal

Aberdeen Proving Ground, Maryland

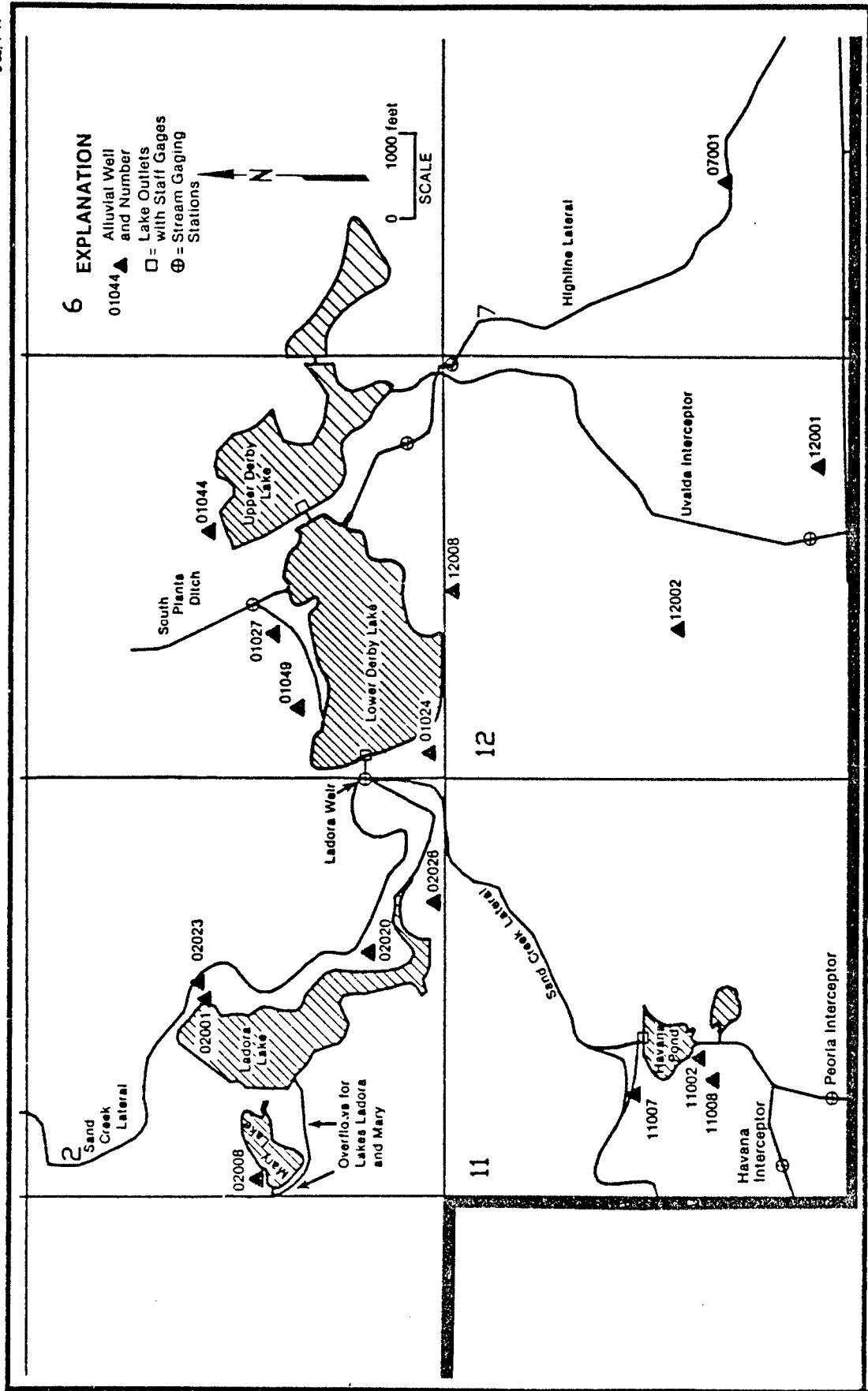


Figure 2.3-3

Prepared for:

U.S. Army Program Manager's Office

SURFACE WATER FEATURES AND ALLUVIAL WELLS

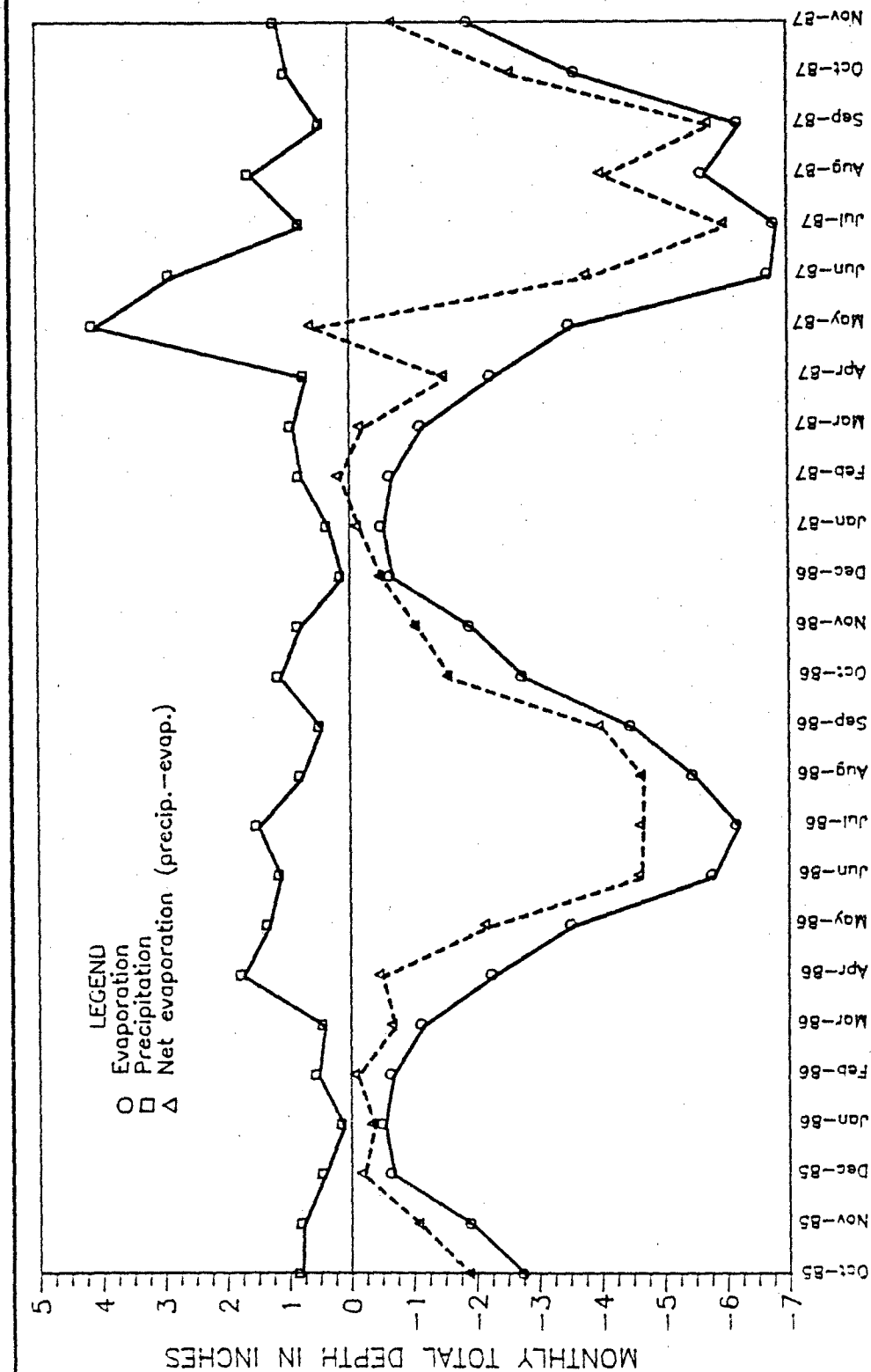
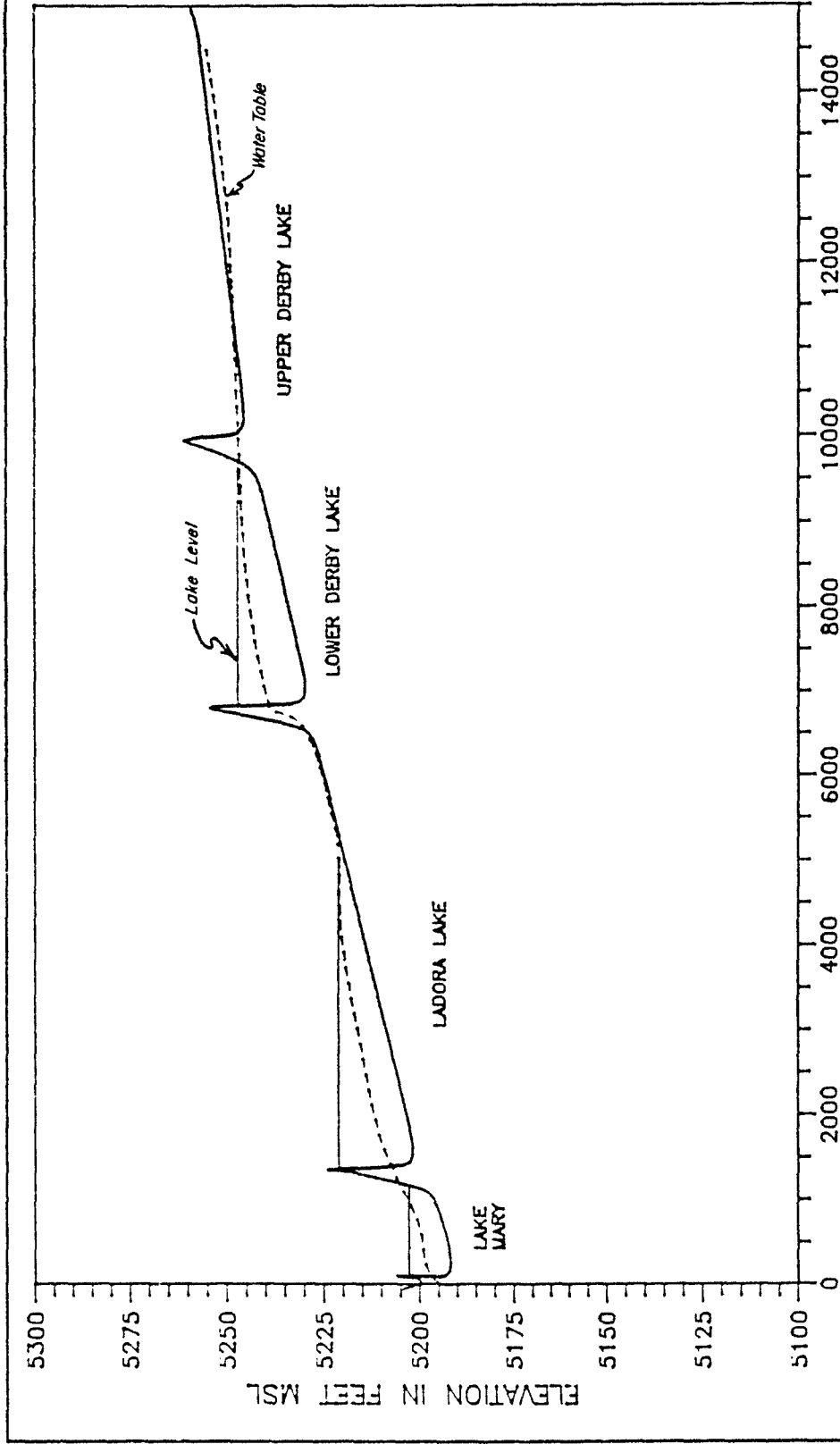


Figure 2.3-4

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal

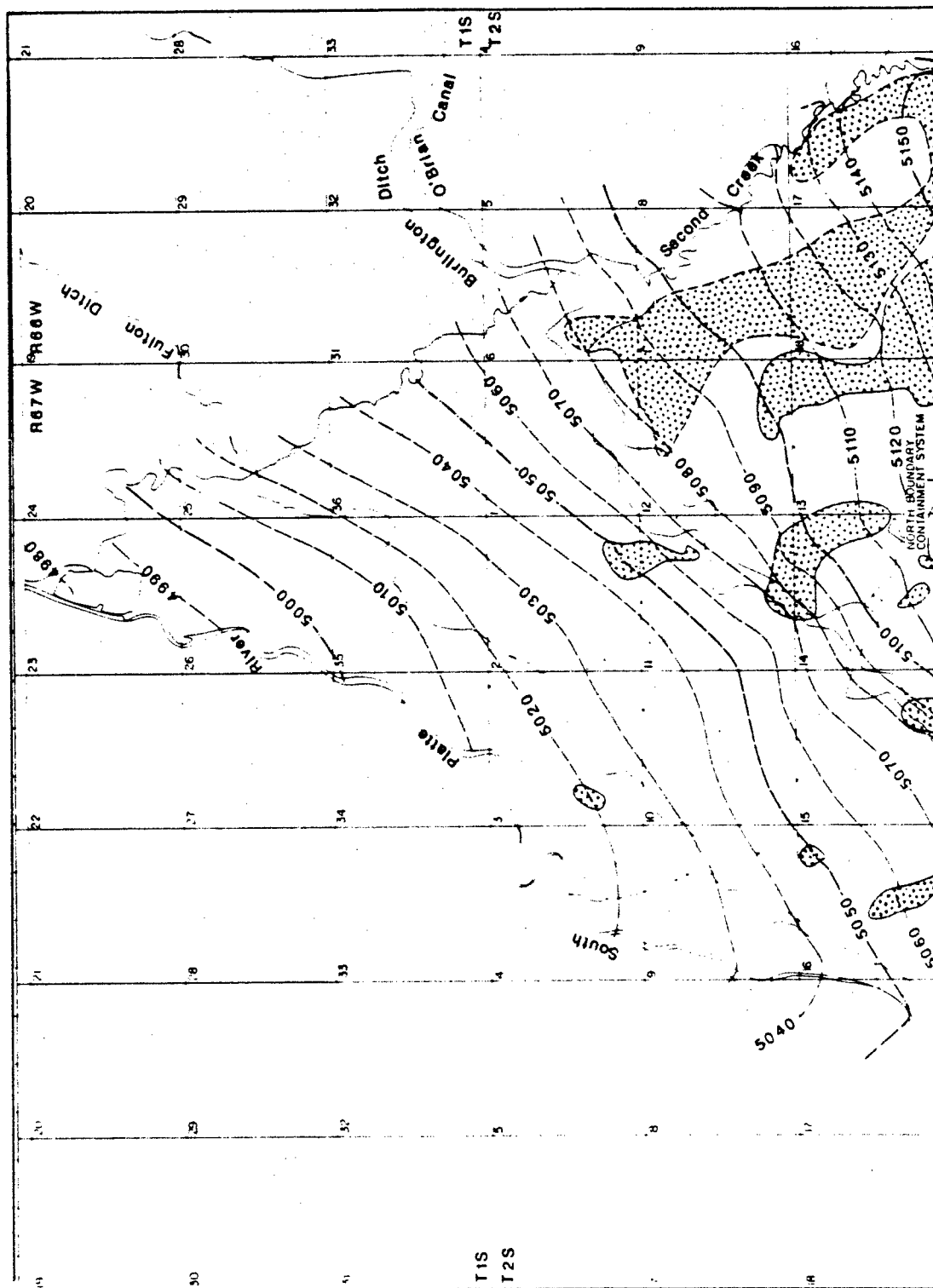
MONTHLY EVAPORATION, PRECIPITATION AND NET EVAPORATION
VALUES FOR THE RMA VICINITY

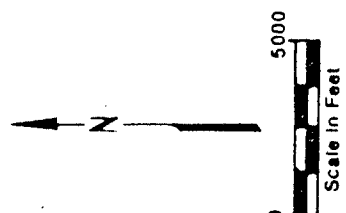


Note : Watertable elevations were taken from summer 1987 watertable map and
 surface elevations from contour map and embankment design plans

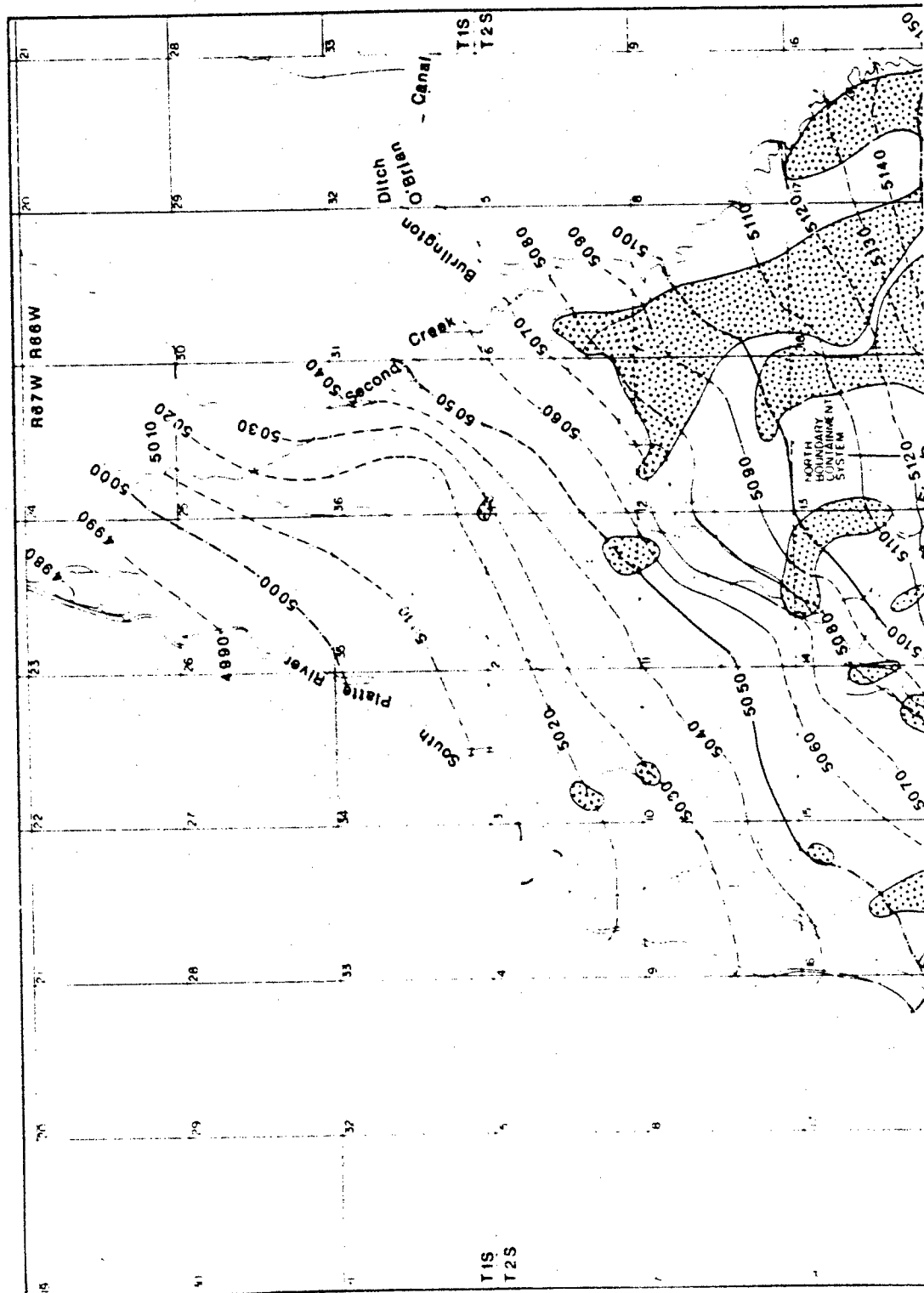
Figure 2.3-5

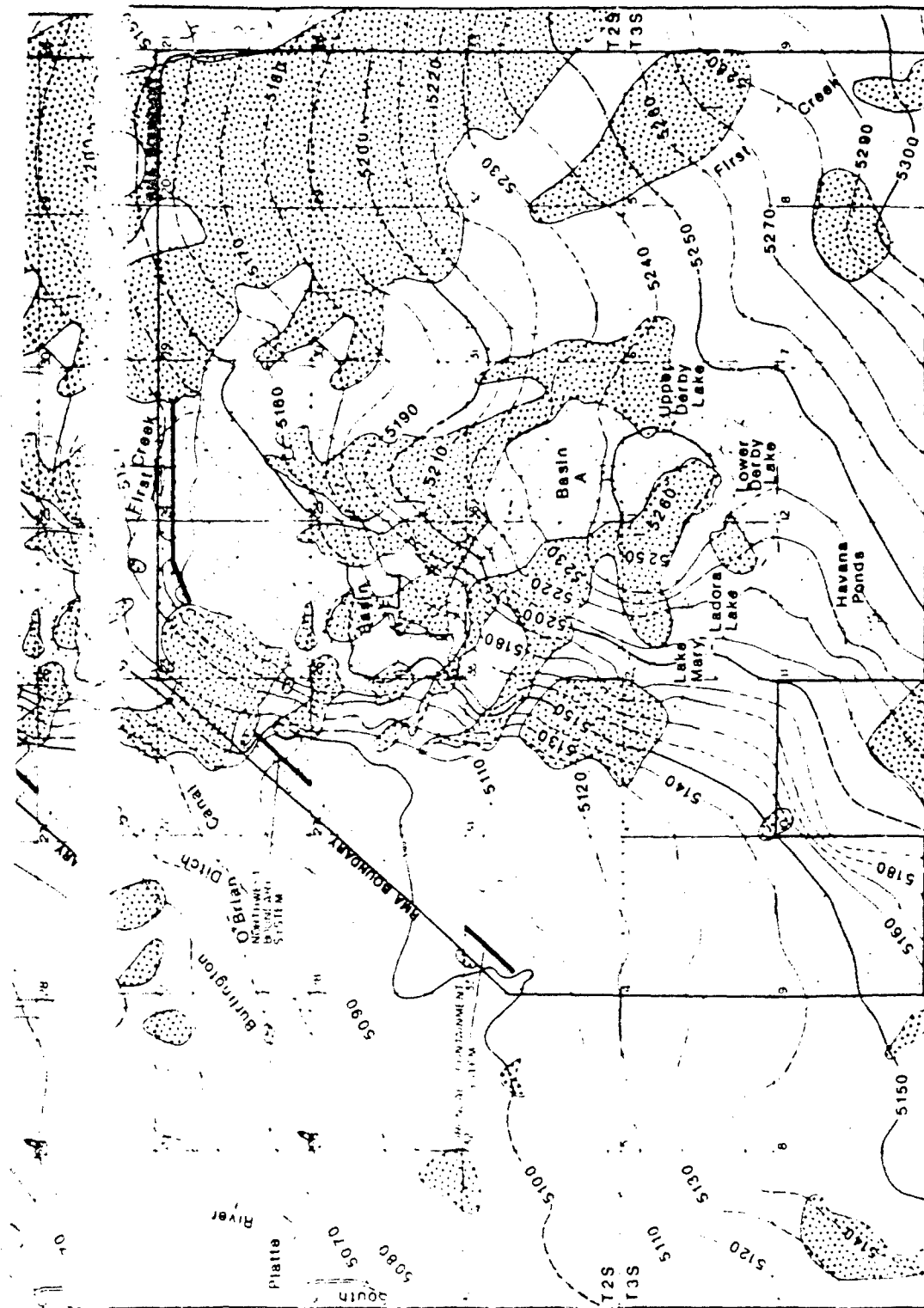
PREPARED FOR:
 U.S. Army Program Manager's Office
 For Rocky Mountain Arsenal





Prepared for:





EXPLANATION

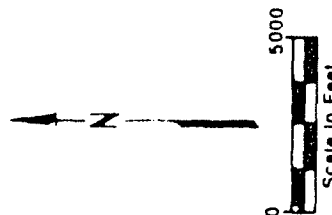
Contour Interval Equals 10 Feet

Unsaturated Alluvium

Inferred Contour

Interpreted Contour

Groundwater Monitoring Well



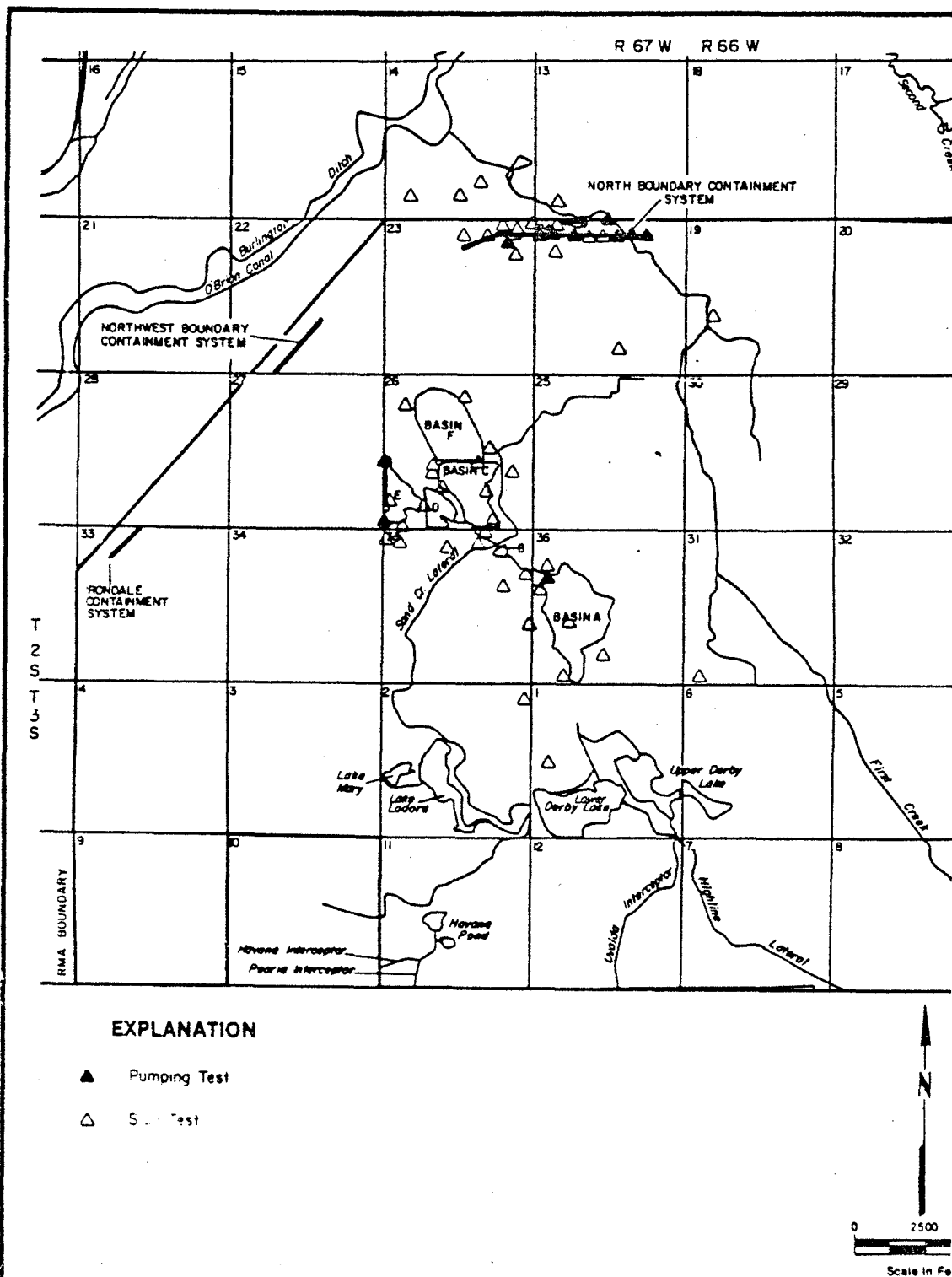


Figure 2.4-3

LOCATIONS OF DENVER FORMATION AQUIFER TESTS

SOURCE: Hunter/ESE, 1988

Prepared for:
U.S. Army Program Manager's
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland

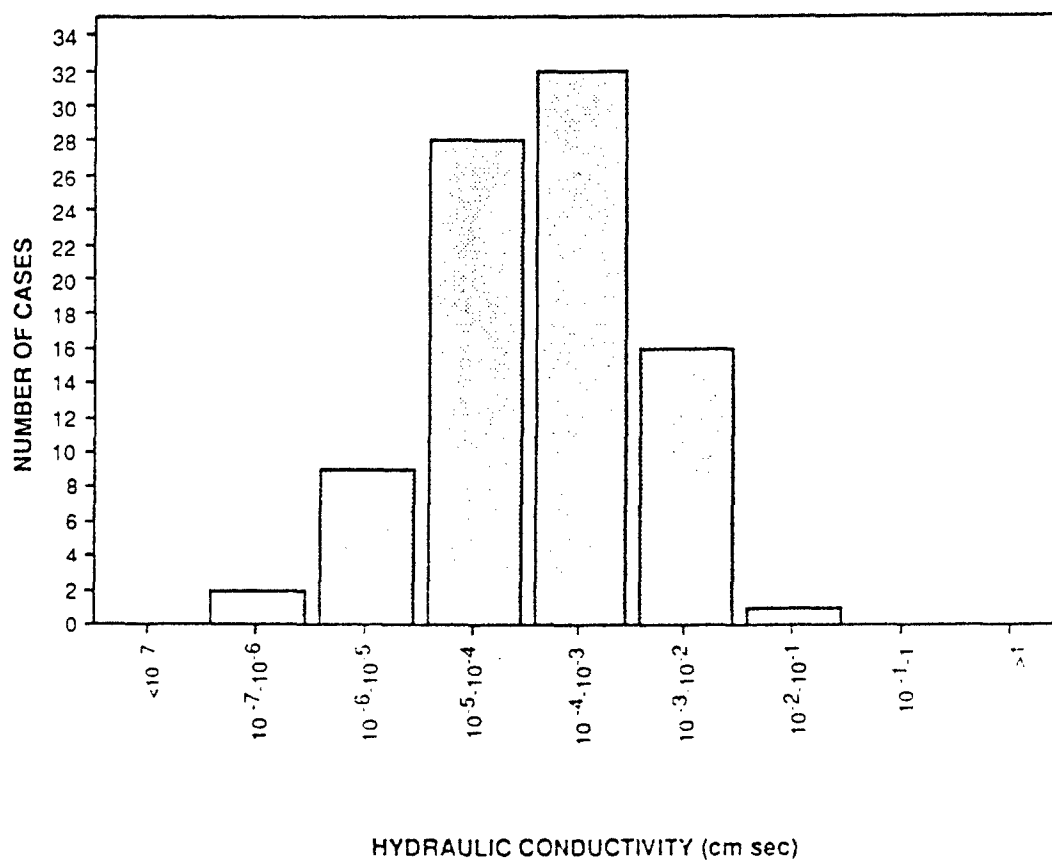
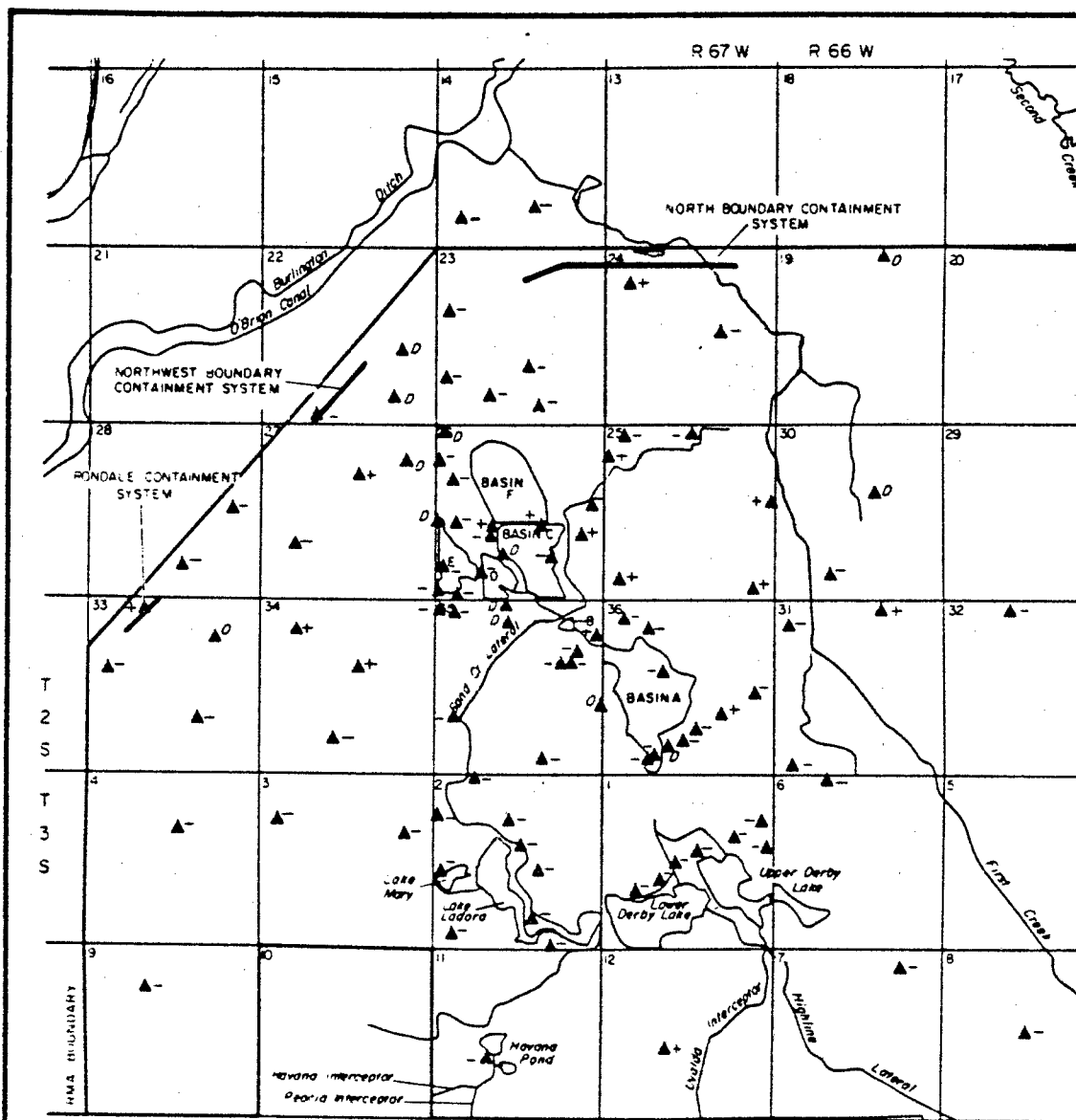


Figure 2.4-4
HYDRAULIC CONDUCTIVITY HISTOGRAM,
SLUG TESTS IN DENVER SANDS

SOURCE: HUNTRESS, 1988

Prepared for:
U.S. Army Program Manager's
For Rocky Mountain Arsenal

Aberdeen Proving Ground, Maryland



EXPLANATION

- Downward Vertical Hydraulic Gradient
- + Upward Vertical Hydraulic Gradient
- O Zero Vertical Hydraulic Gradient
- D Dry Alluvial Well
- ▲ Cluster Well Site

Note:

Direction Of Vertical Hydraulic Gradient Determined From Third Quarter 1987 Water Level Data. If Unavailable, Most Recent Water Level Data Were Used.



Figure 2.4-5

DIRECTION OF VERTICAL HYDRAULIC GRADIENTS BETWEEN ALLUVIAL/UNCONFINED AND DENVER WELLS AT CLUSTER SITES.

SOURCE Hunter/ESE, 1988

Prepared for:

U.S. Army Program Manager's
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland

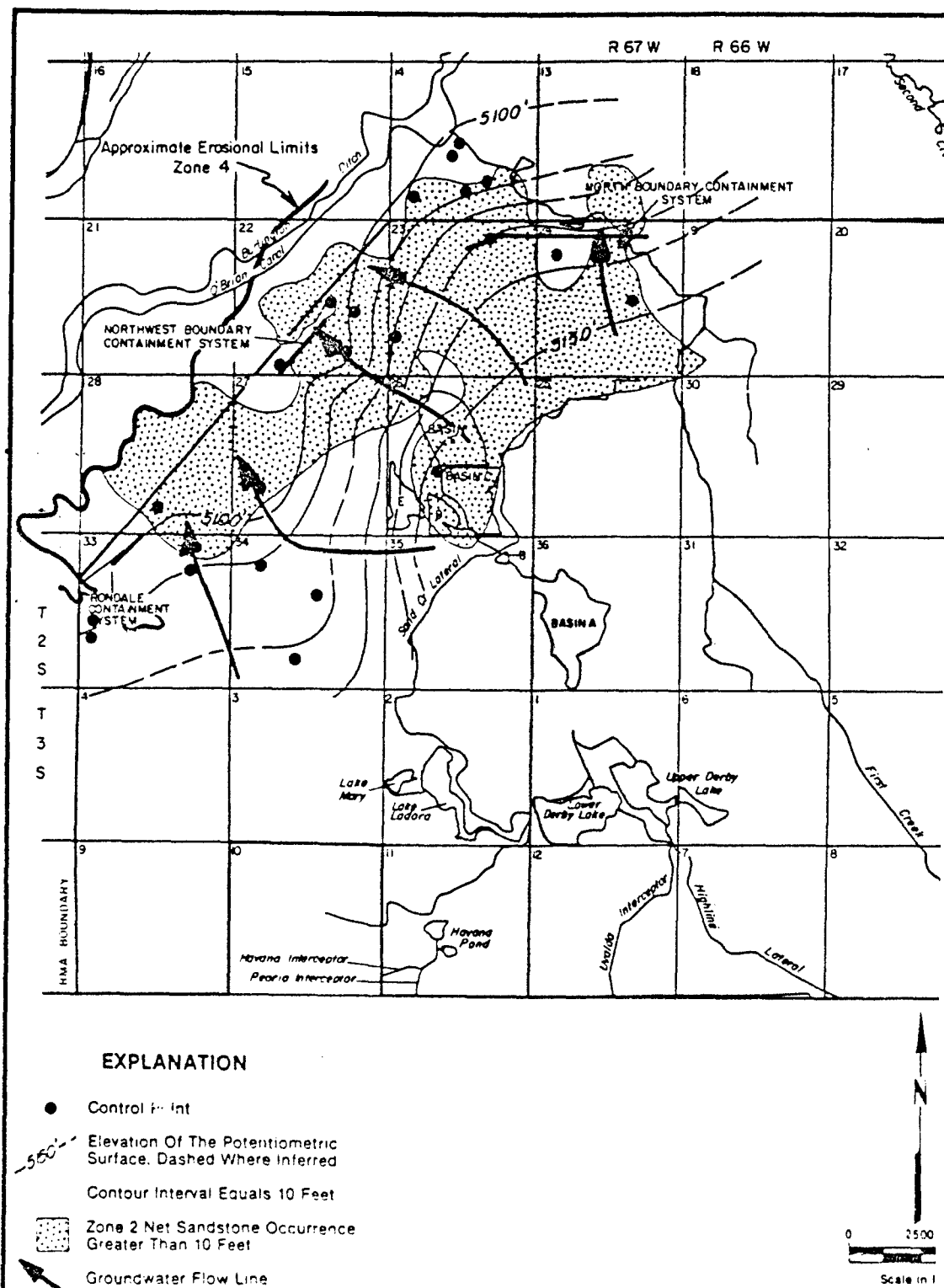
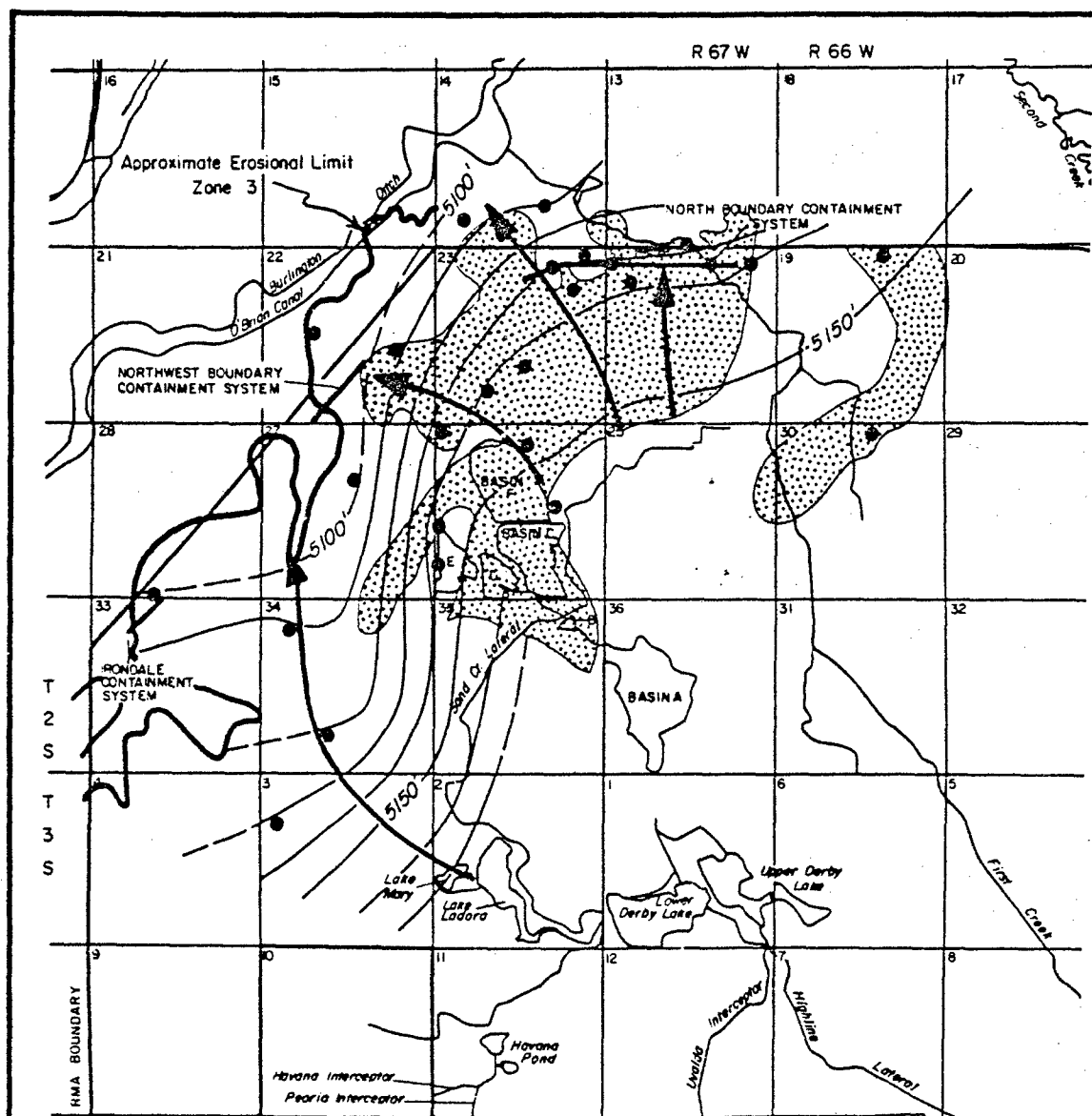


Figure 2.4-6

POTENTIOMETRIC SURFACE OF DENVER
ZONE 4, 3RD QUARTER FY 1987

SOURCE: Hunter/ES&E, 1988

Prepared for:
U.S. Army Program Manager's
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland



EXPLANATION

- Control Point
- 5150' — Elevation Of The Potentiometric Surface, Dashed Where Inferred
- Contour Interval Equals 10 Feet
- ▨ Zone 2 Net Sandstone Occurrence Greater Than 10 Feet
- Groundwater Flow Line



Figure 2.4-7

POTENTIOMETRIC SURFACE OF DENVER
ZONE 3, 3RD QUARTER FY 1987

SOURCE: Hunter/ESE, 1988

Prepared for:
U.S. Army Program Manager's
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland

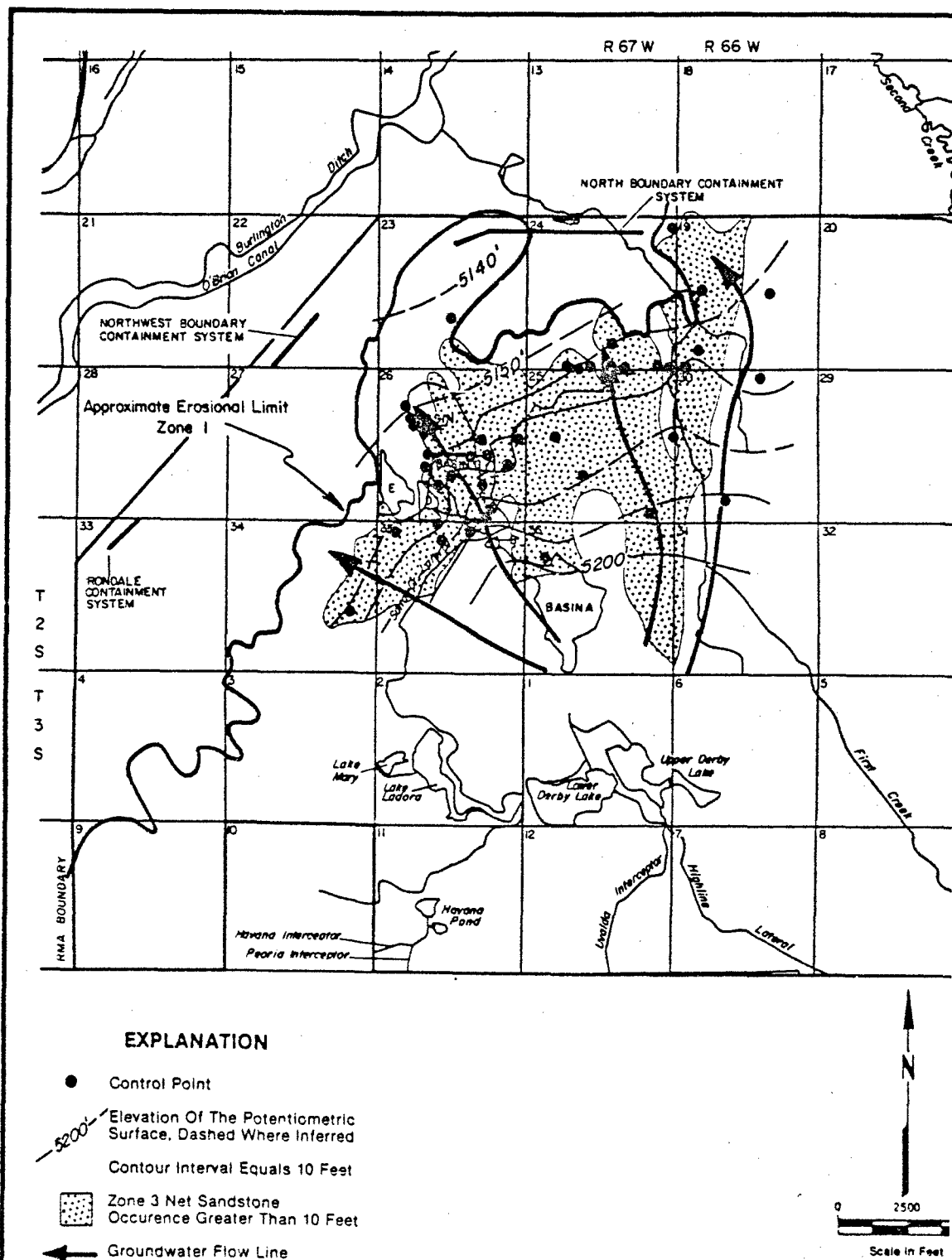
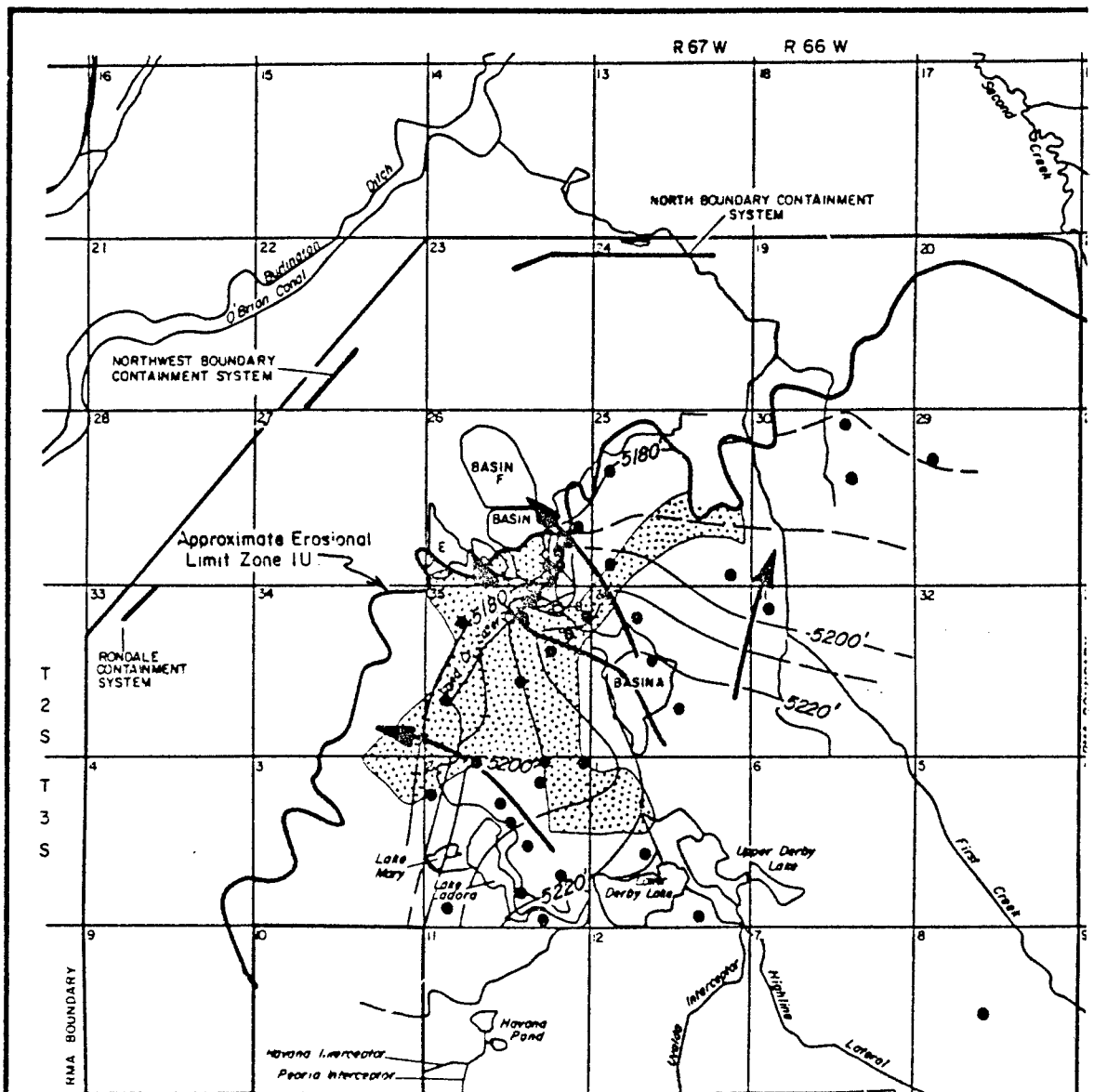


Figure 2.4-9

POTENTIOMETRIC SURFACE OF DENVER
ZONE 1, 3RD QUARTER FY 1987

SOURCE: Hunter/ESE, 1988

Prepared for:
U.S. Army Program Manager's C
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland



EXPLANATION

- Control Point
- 5220'--- Elevation Of The Potentiometric Surface. Dashed Where Inferred
- Contour Interval Equals 10 Feet
- Zone 1U Net Sandstone Occurrence Greater Than 10 Feet
- Groundwater Flow Line



Figure 2.4-10

POTENTIOMETRIC SURFACE OF DENVER
ZONE 1U, 3RD QUARTER FY 1987

SOURCE: Hunter/ESE, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland

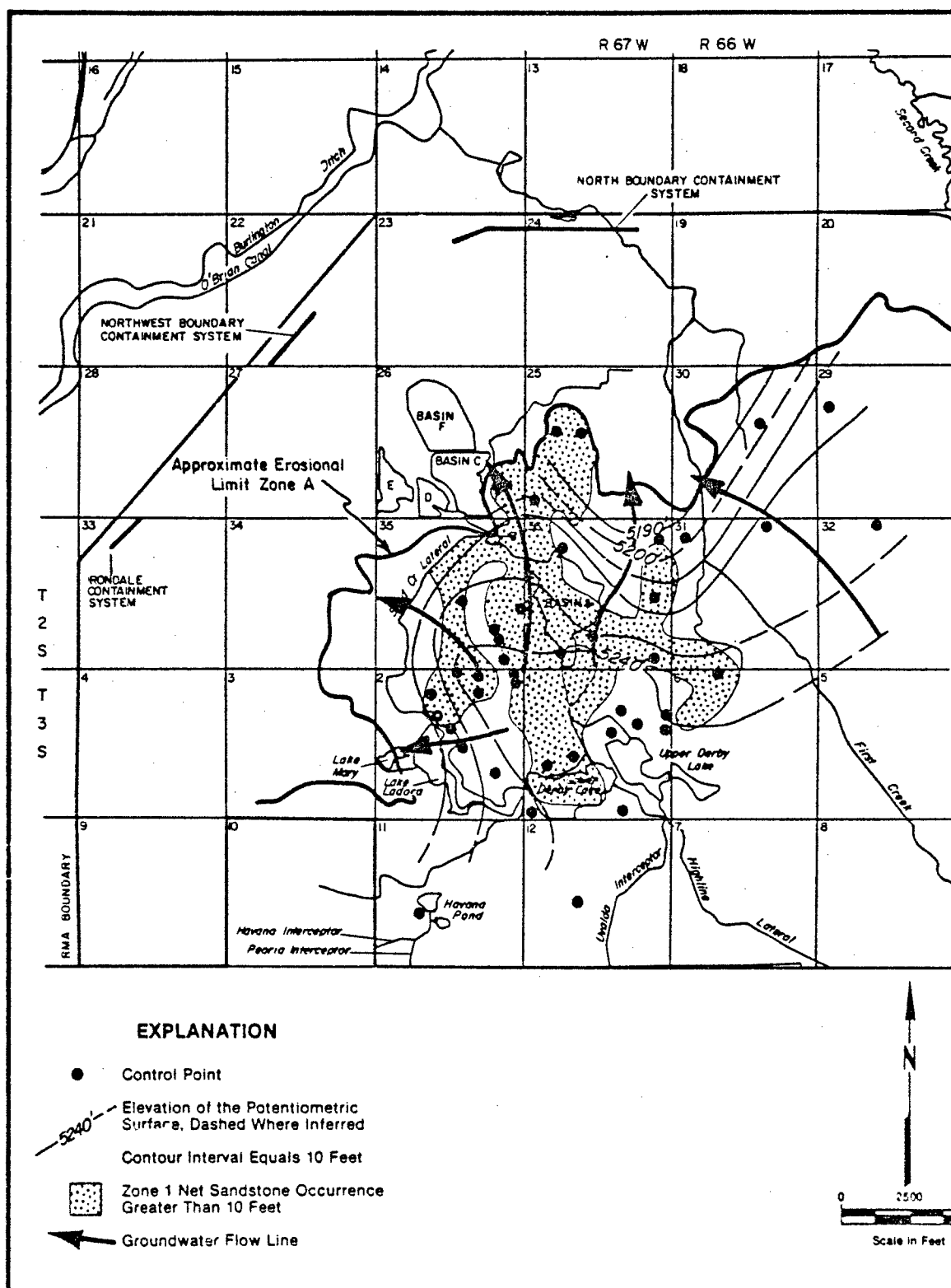
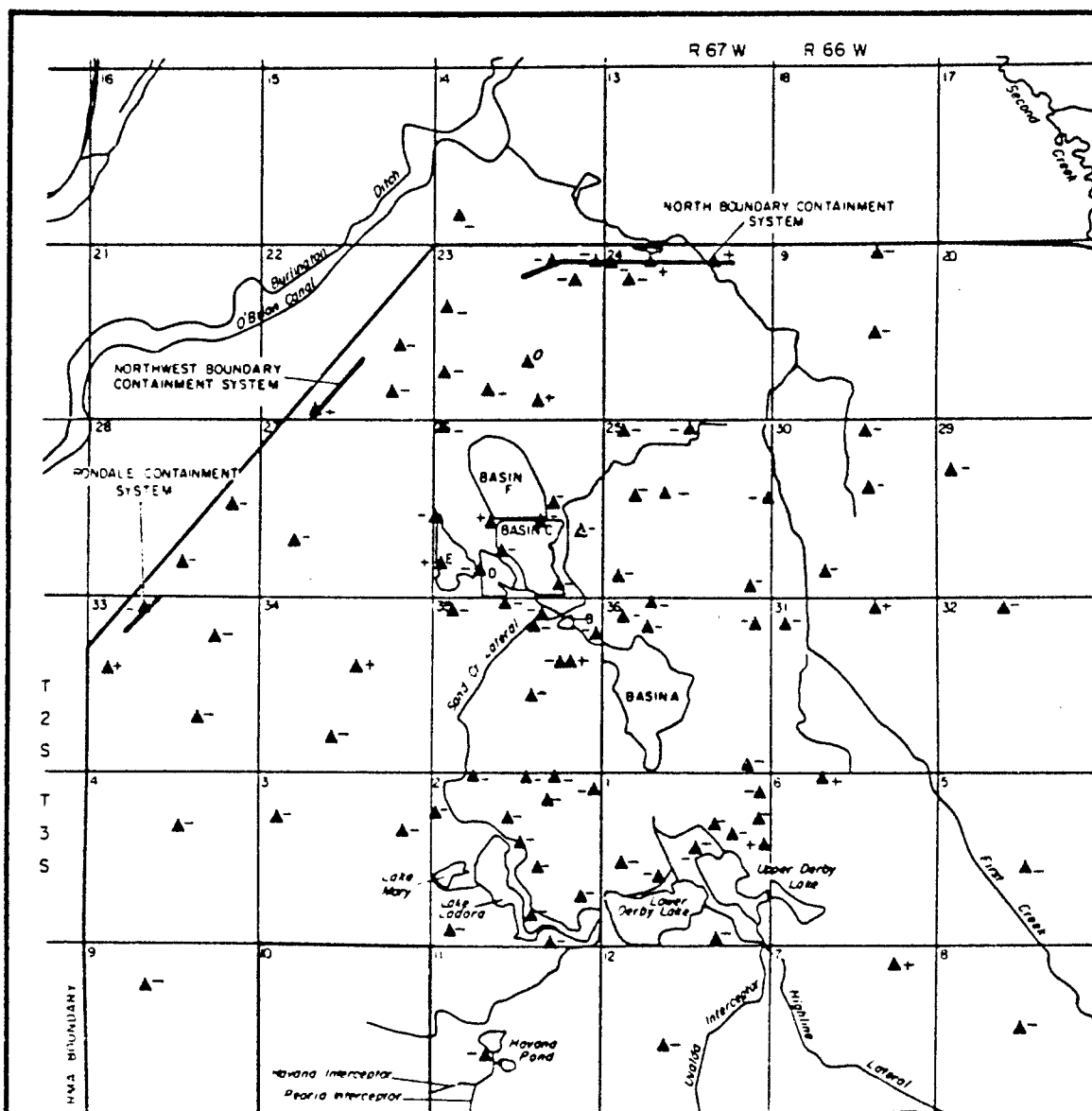


Figure 2.4-11

POTENTIOMETRIC SURFACE OF DENVER
ZONE A, 3RD QUARTER FY 1987

SOURCE: Hunter/ESE, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland



EXPLANATION

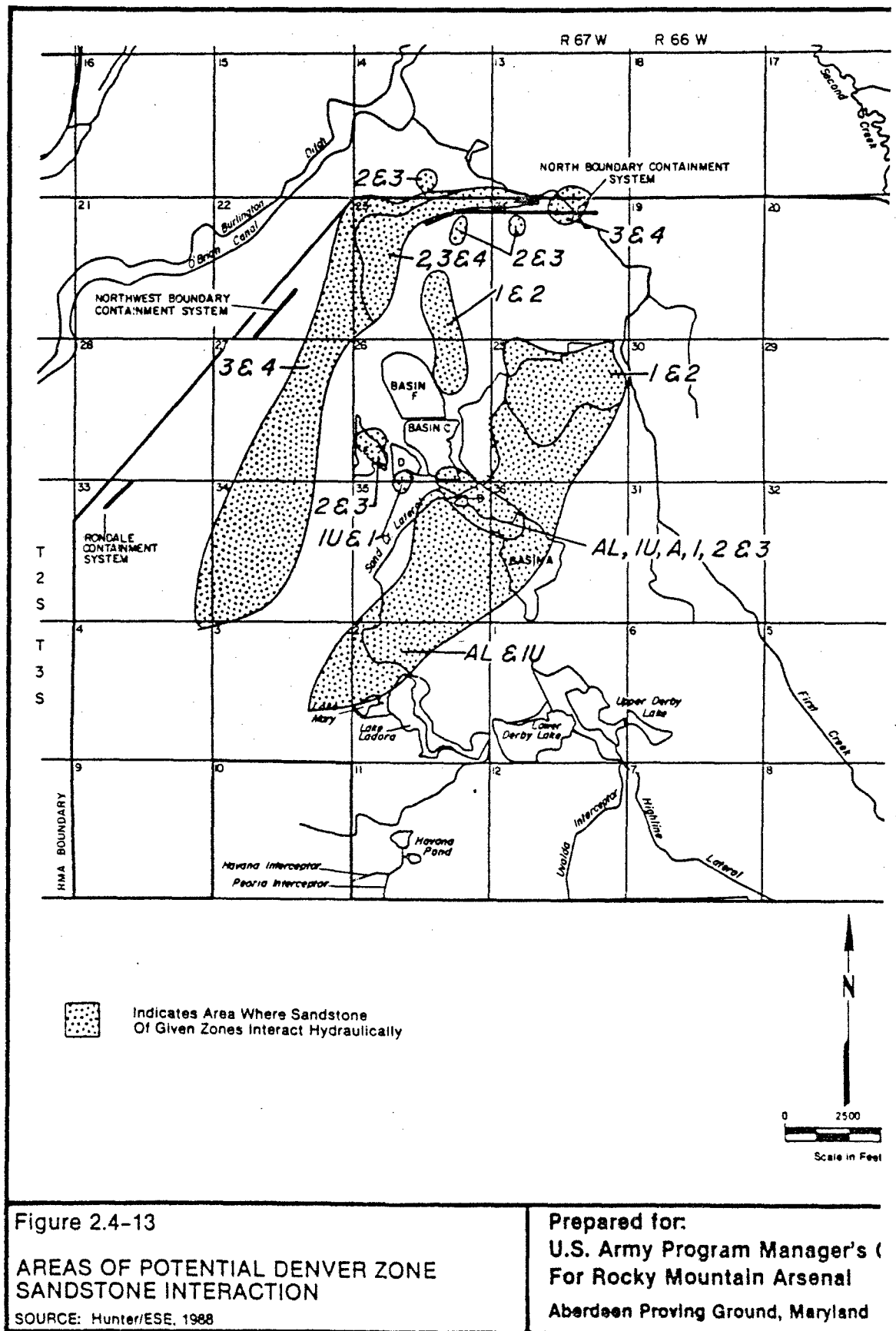
- Downward Vertical Hydraulic Gradient
- + Upward Vertical Hydraulic Gradient
- O Zero Vertical Hydraulic Gradient
- ▲ Cluster Well Site

Note:
Direction Of Vertical Hydraulic Gradient
Determined From Third Quarter 1987 Water
Level Data. If Unavailable, Most Recent
Water Level Data Were Used.

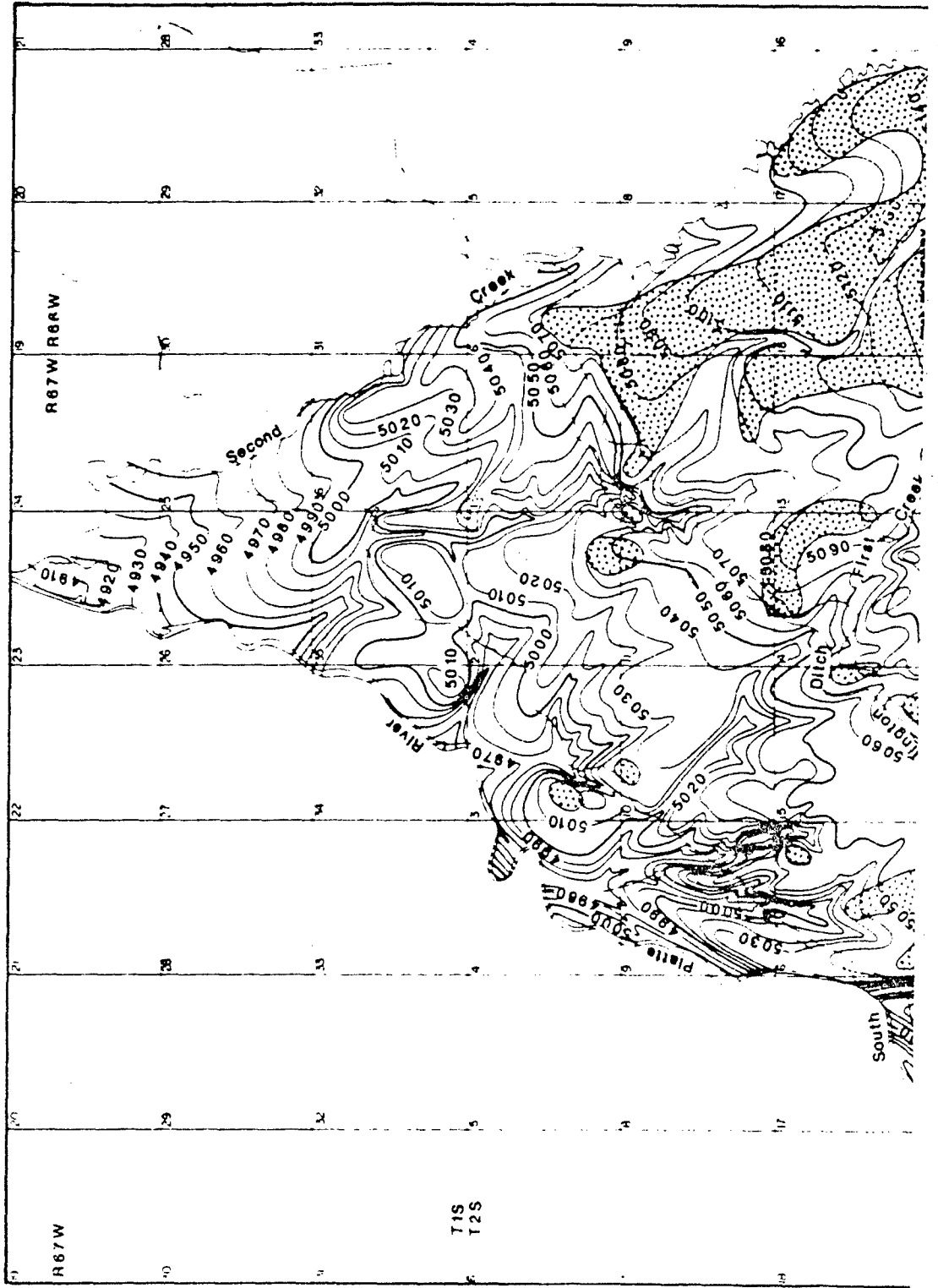
Figure 2.4-12
DIRECTION OF VERTICAL HYDRAULIC
GRADIENTS BETWEEN DENVER WELLS
AT CLUSTER SITES

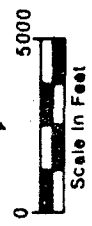
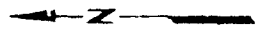
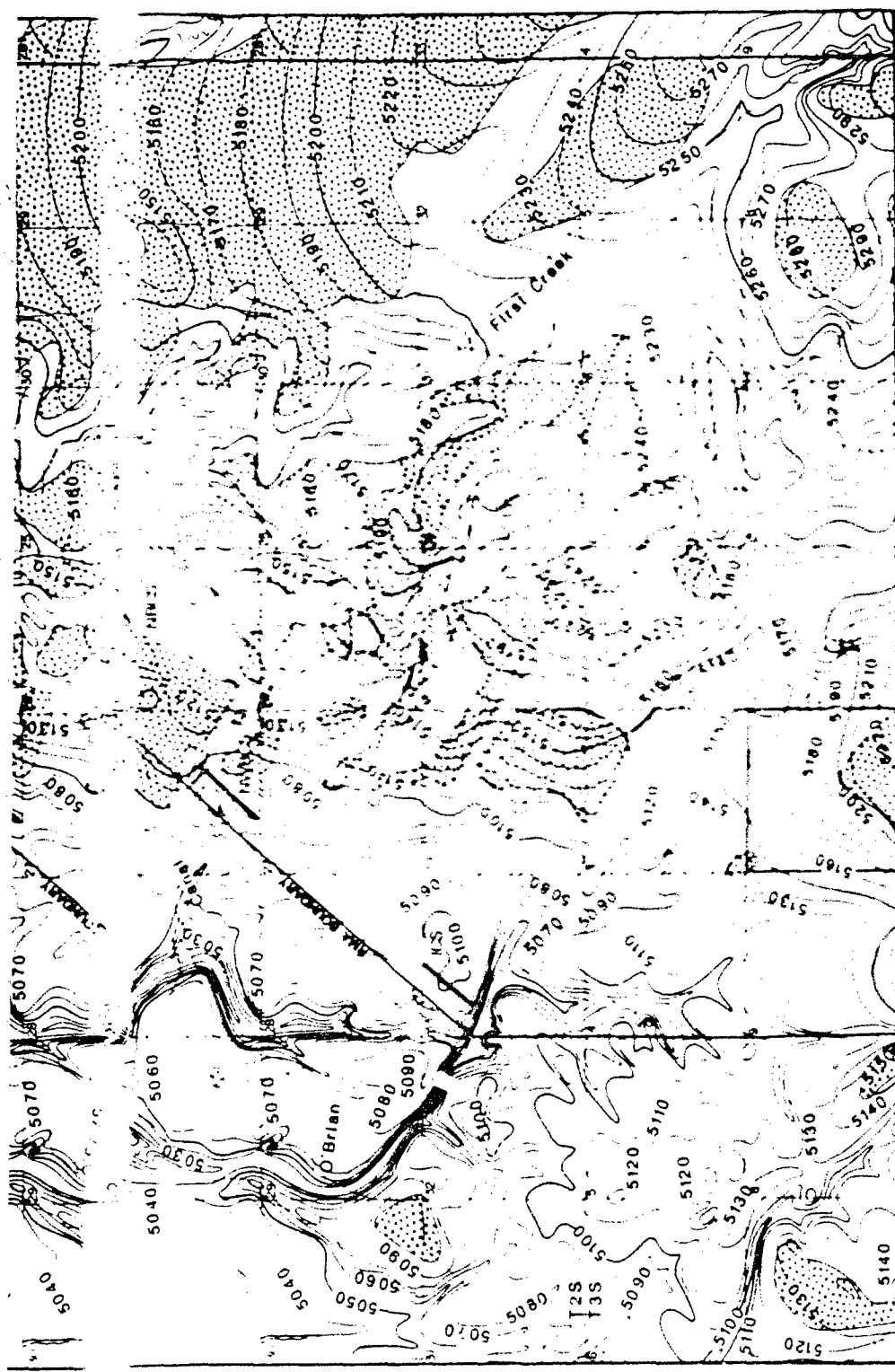
SOURCE: Hunter/ESE, 1988

Prepared for:
U.S. Army Program Manager's C
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland



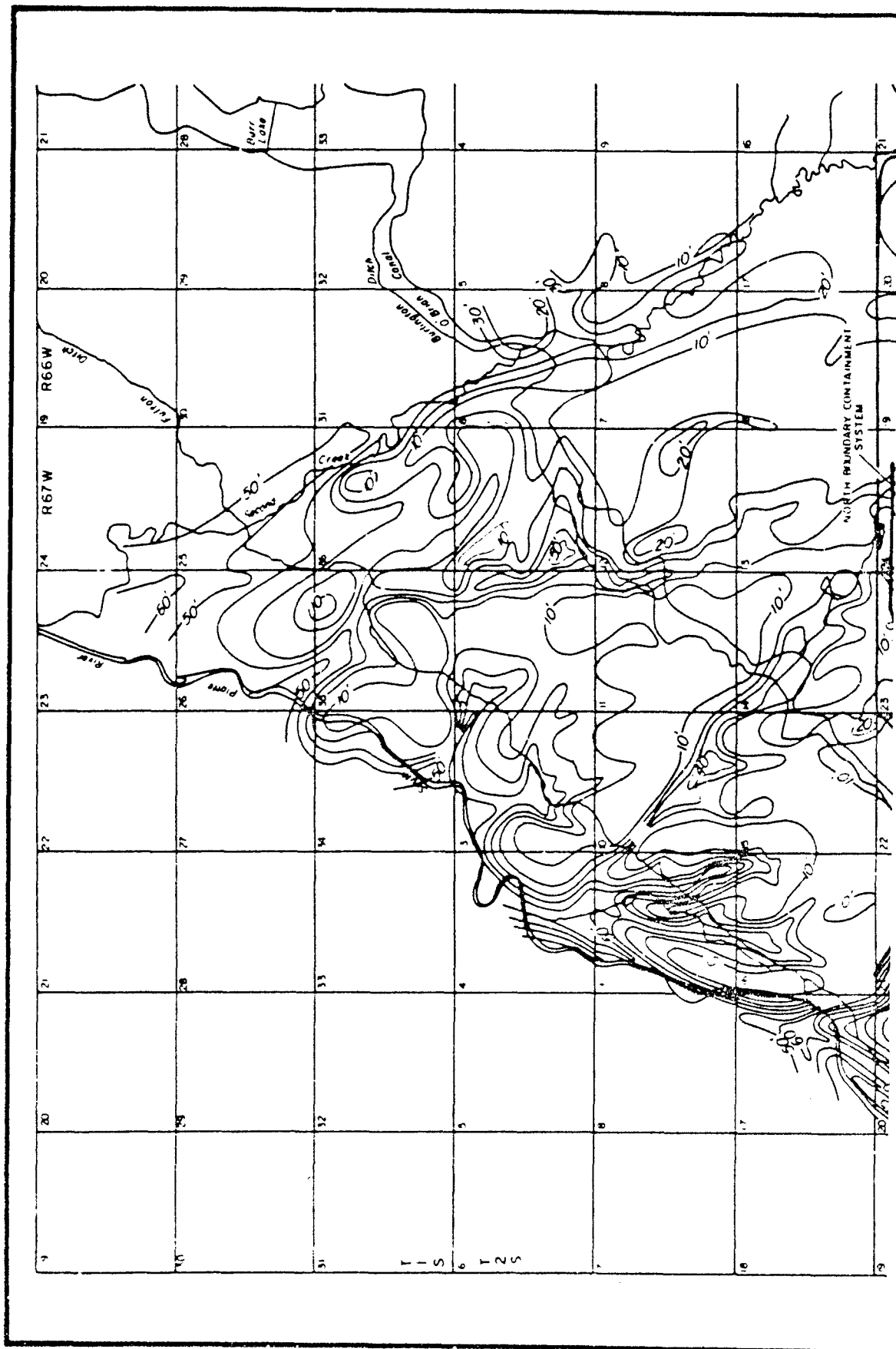
848, T 44

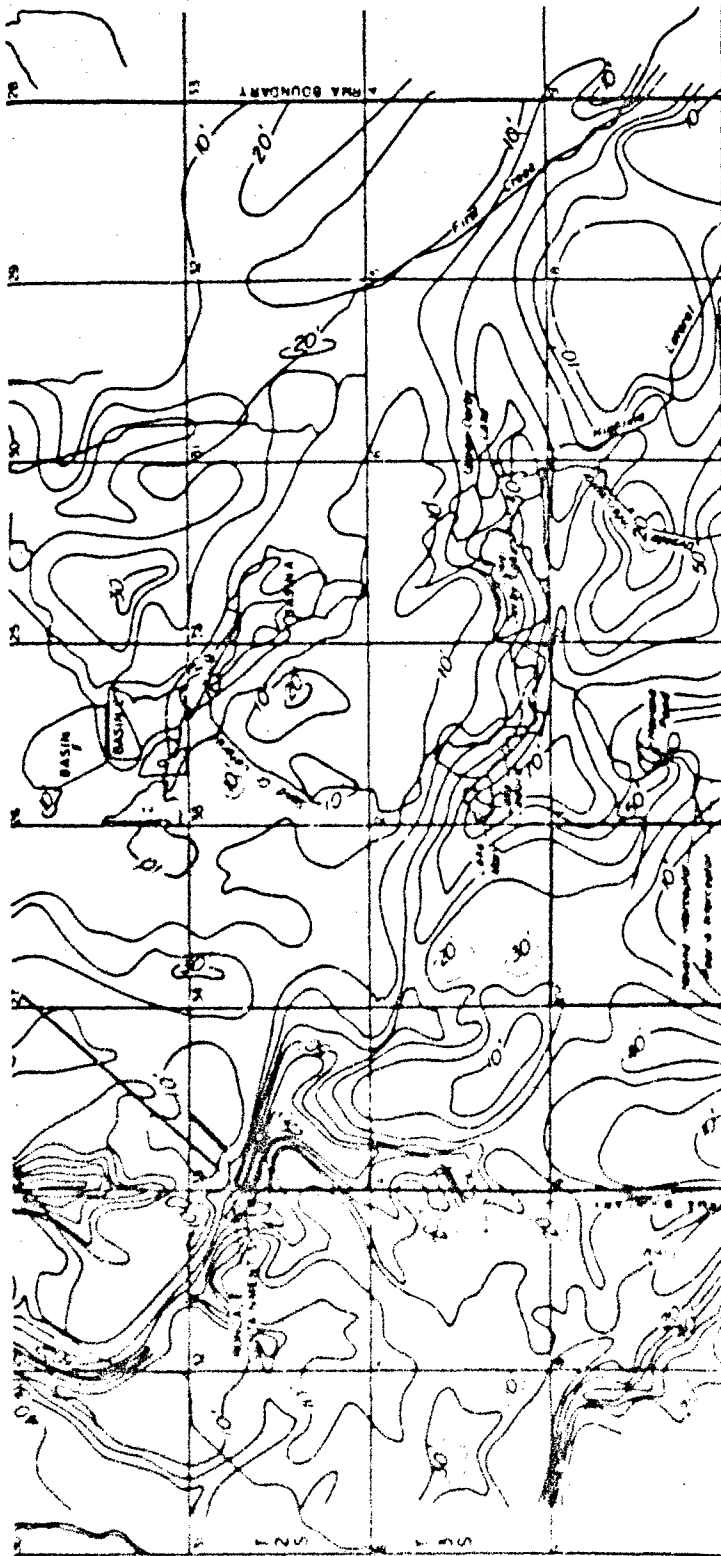




EXPLANATION

- Contour Interval Equals 10 Feet
- ICS Irondale Containment System
- Unsat. Areas From Time Averaged Water Table Map
- NBCS North Boundary Containment System
- NWBCS Northwest Boundary Containment System





EXPLANATION

Contour Interval Equals 10 feet

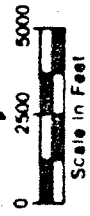


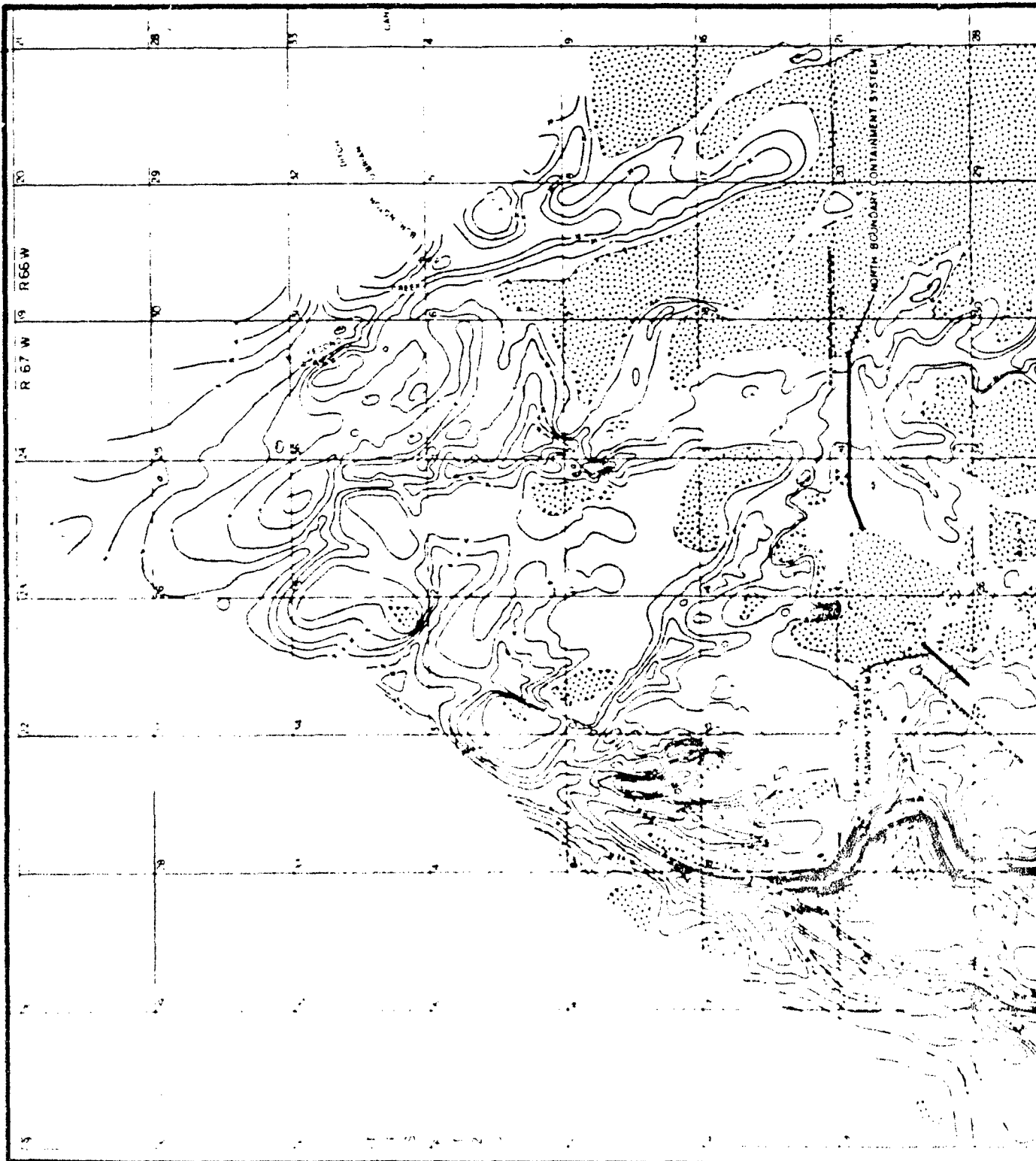
Figure 2.4-15

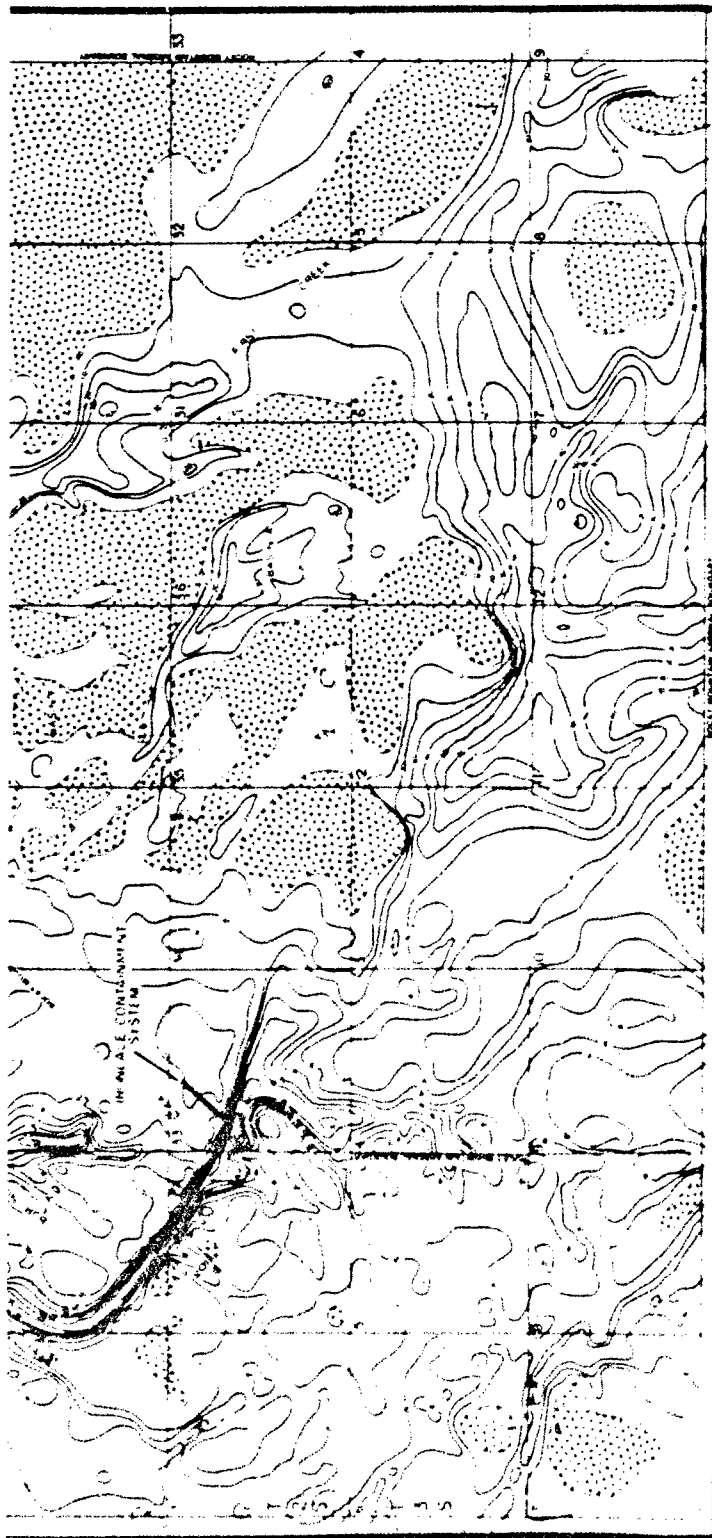
SATURATED THICKNESS MAP FOR UNCONFINED FLOW SYSTEM

SOURCE: M.A. 1958

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal

Aberdeen Proving Ground, Maryland





EXPLANATION

Contour Interval Equals 10 Feet


 Unsaturated Alluvium

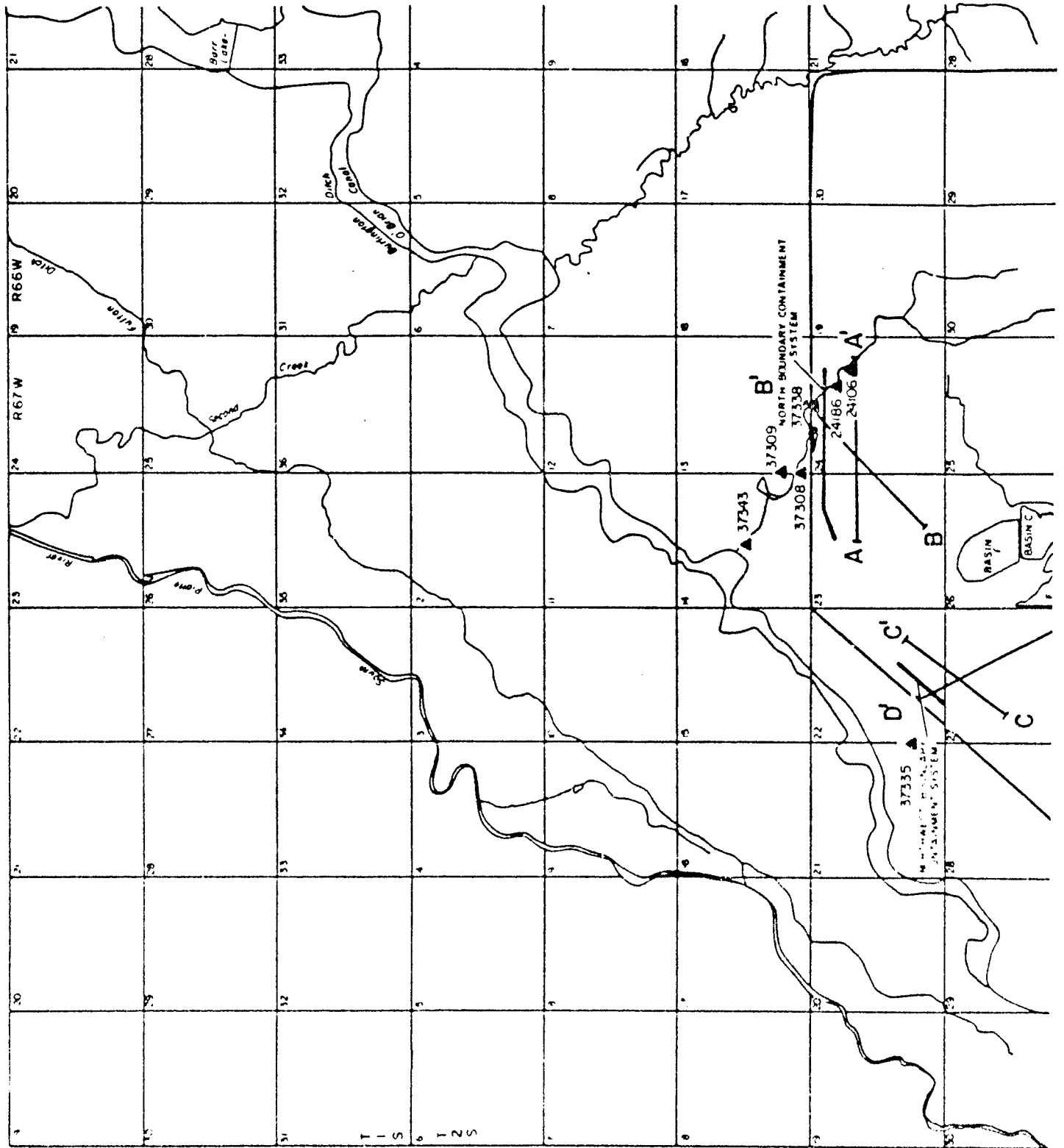
Figure 2.4-16.

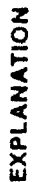
SATURATED THICKNESS OF ALLUVIAL MATERIAL

SOURCE Hunter-ESE, 1988

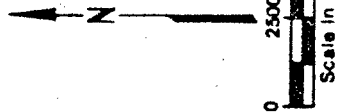
Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal

Aberdeen Proving Ground, Maryland





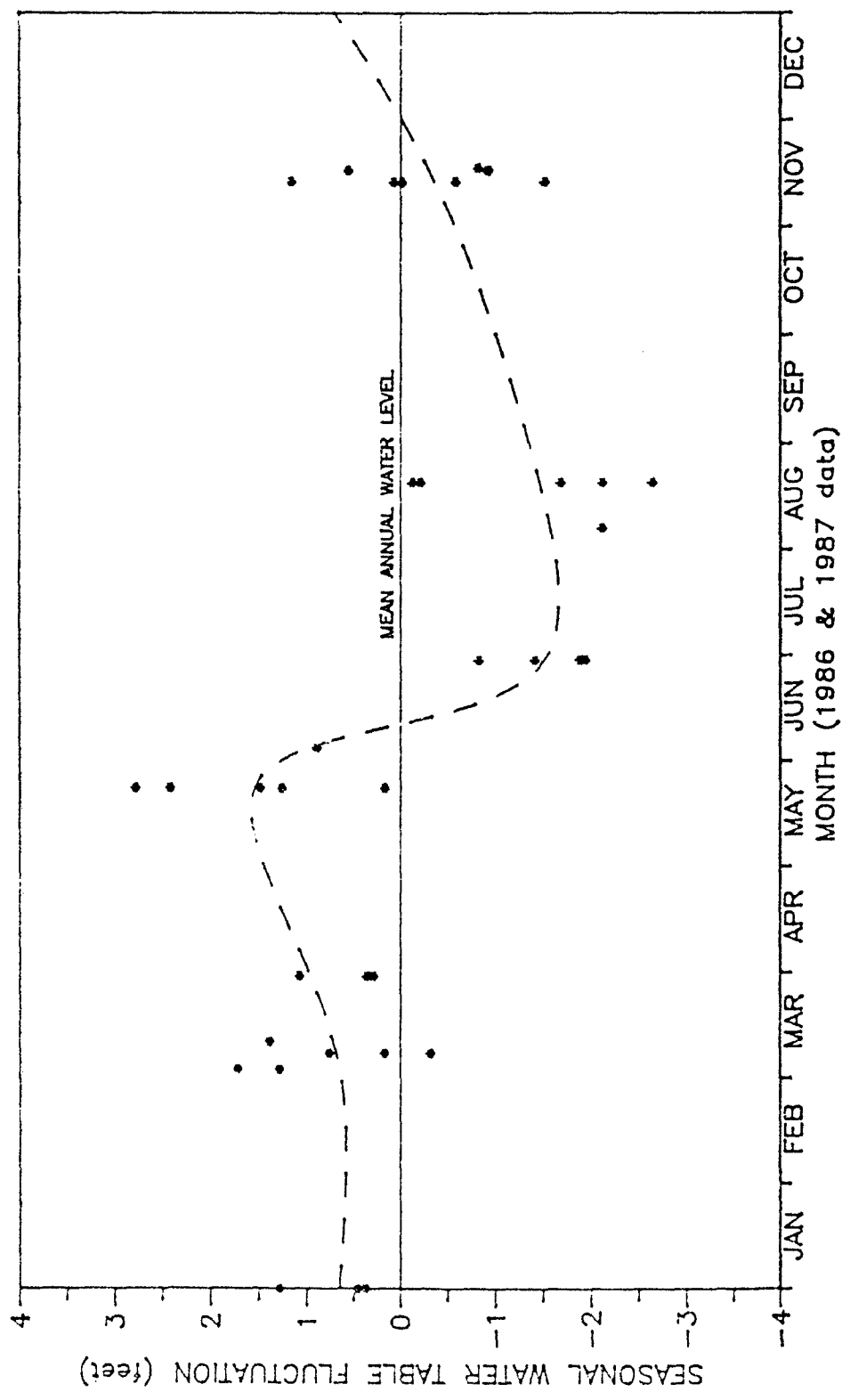
▲ Well Location For Seasonal Hydrograph
A—A' Hydrographic Profile Location



LOCATION OF HYDROGRAPHIC PROFILES AND WELL LOCATIONS FOR SEASONAL HYDROGRAPHS

**Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland**

SOURCE: Hunter/ESE, 1988



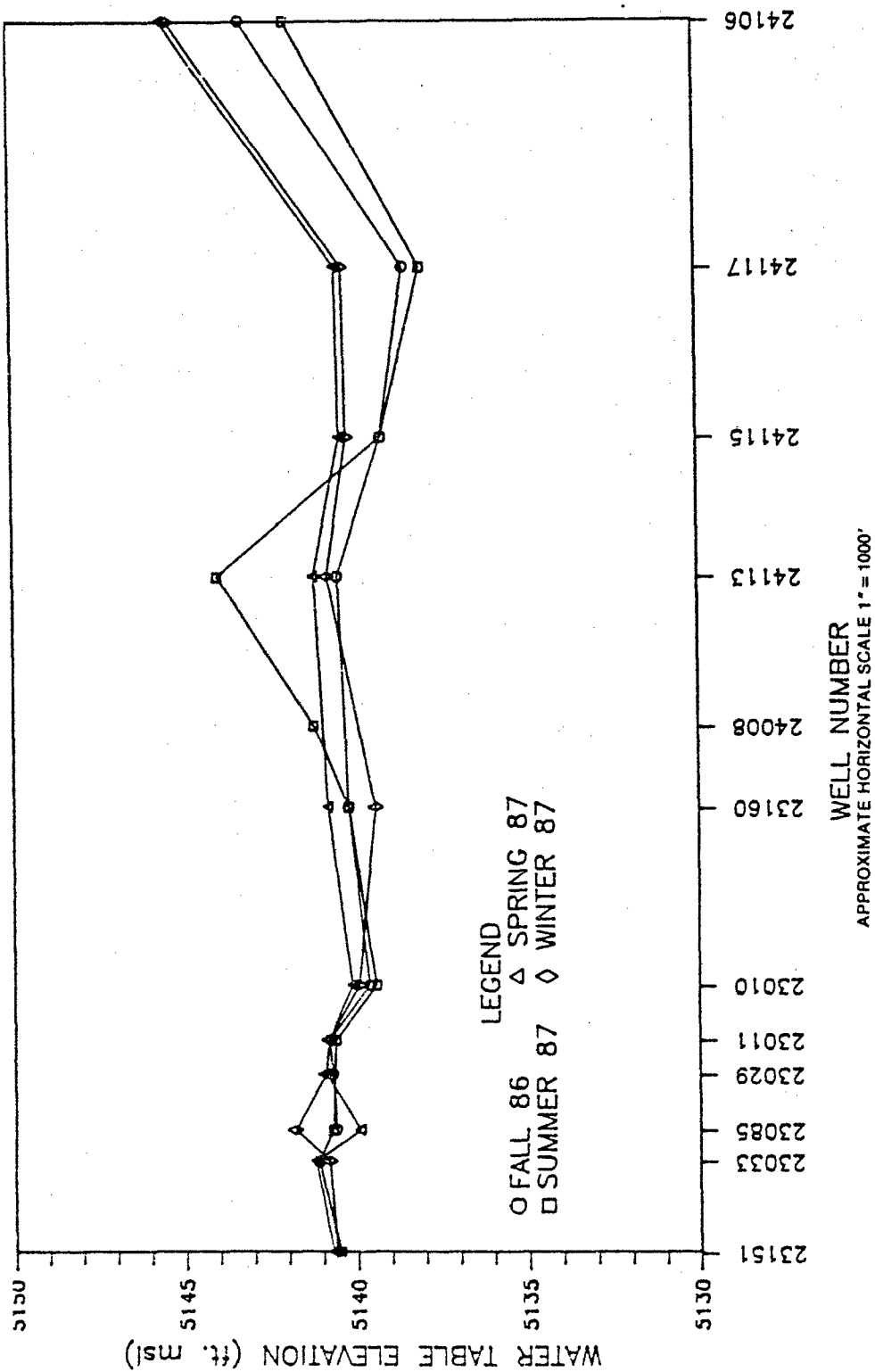
Note : Water levels are for wells 24106, 24187, 37338, 37343, and 37386.

Figure 2.4-18

SEASONAL WATER LEVEL FLUCTUATIONS FOR WELLS NEAR
NORTH FIRST CREEK

SOURCE: Hunter/ESE, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland



Prepared for:
 U.S. Army Program Manager's Office
 For Rocky Mountain Arsenal
 Aberdeen Proving Ground, Maryland

Figure 2.4-19
 HYDROGRAPHIC PROFILE UPGRADIENT OF THE NBCS (LINE A-A')

SOURCE: Hunter/ESE, 1988

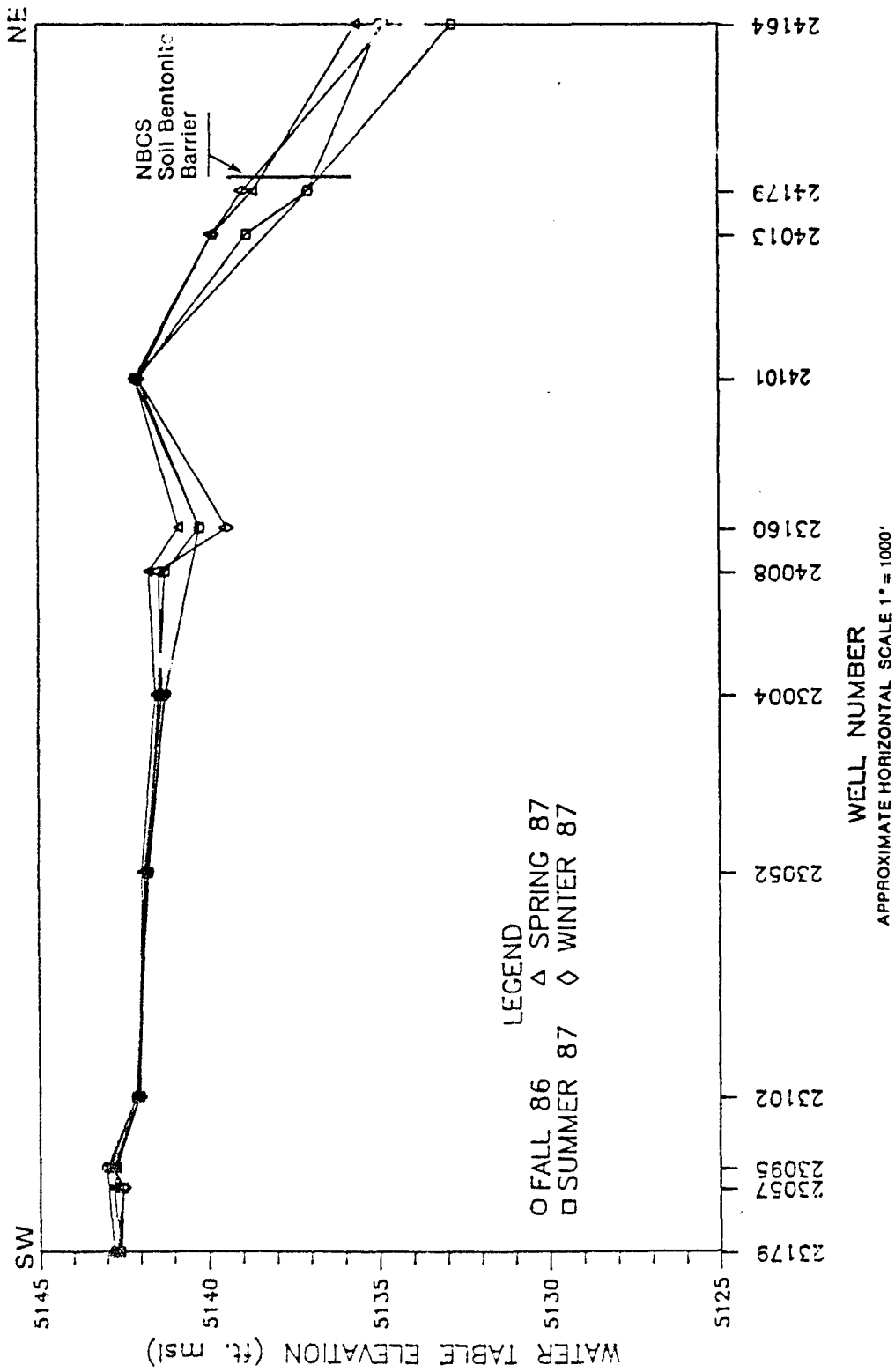
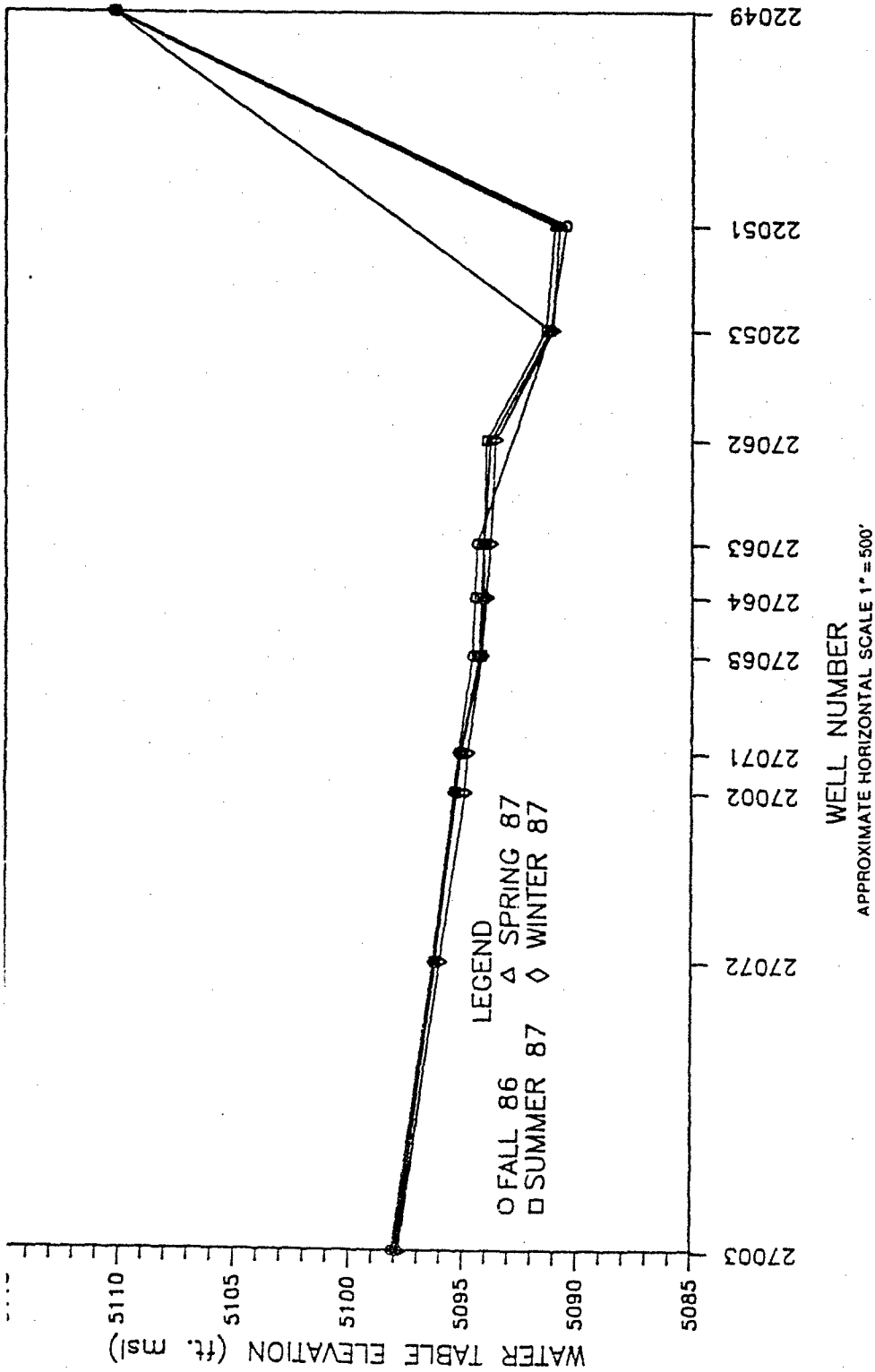


Figure 2.4-20

HYDROGRAPHIC PROFILE THROUGH SECTIONS 23 AND 24, ACROSS THE NBCS (LINE B-B')

SOURCE: Hunter/ESE, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland



Prepared for:
 U.S. Army Program Manager's Office
 For Rocky Mountain Arsenal
 Aberdeen Proving Ground, Maryland

Figure 2.4-21
 HYDROGRAPHIC PROFILE UPGRADIENT OF THE NWBCS (LINE C-C')

SOURCE: Hunter/ESE, 1988

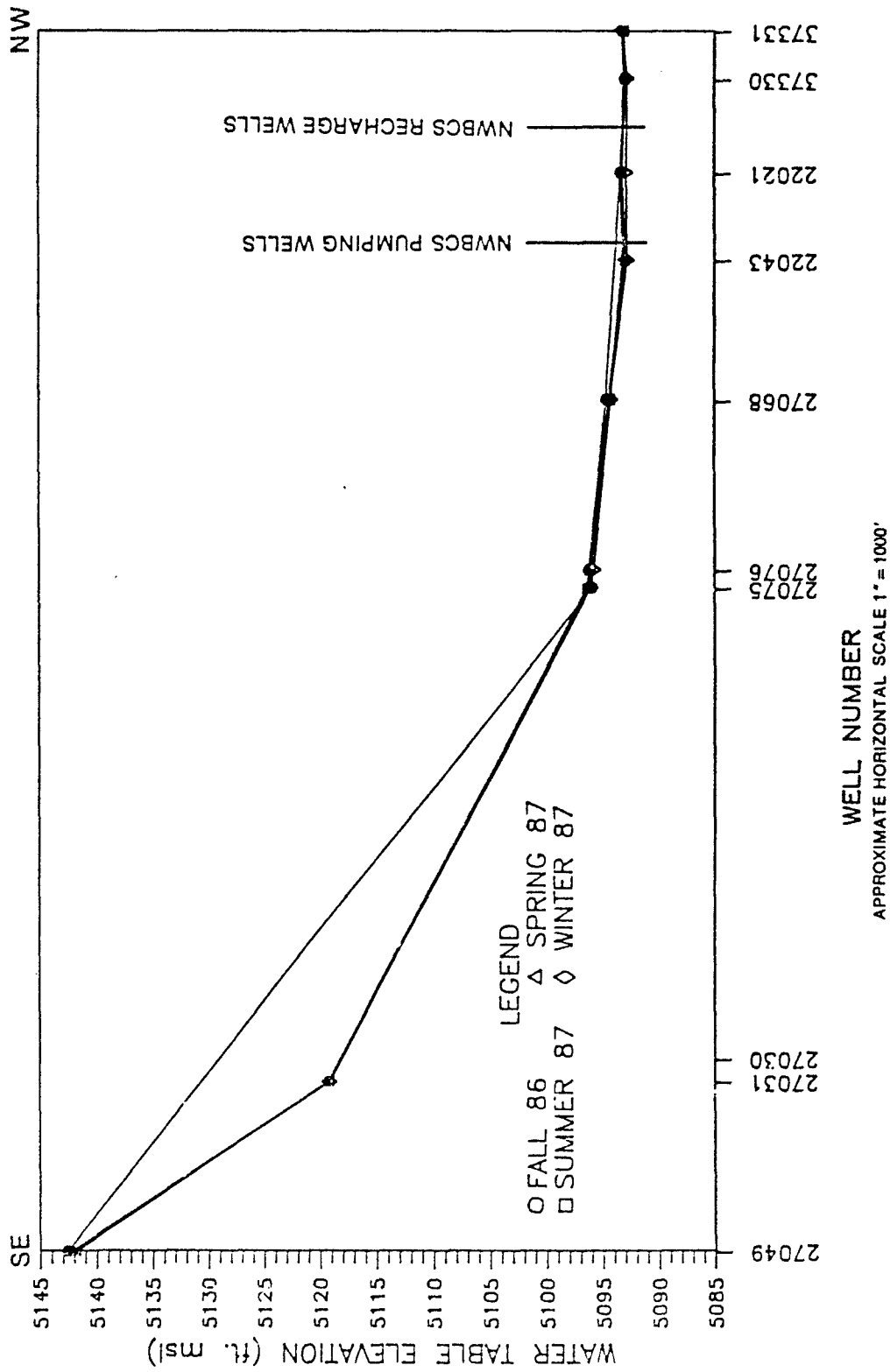
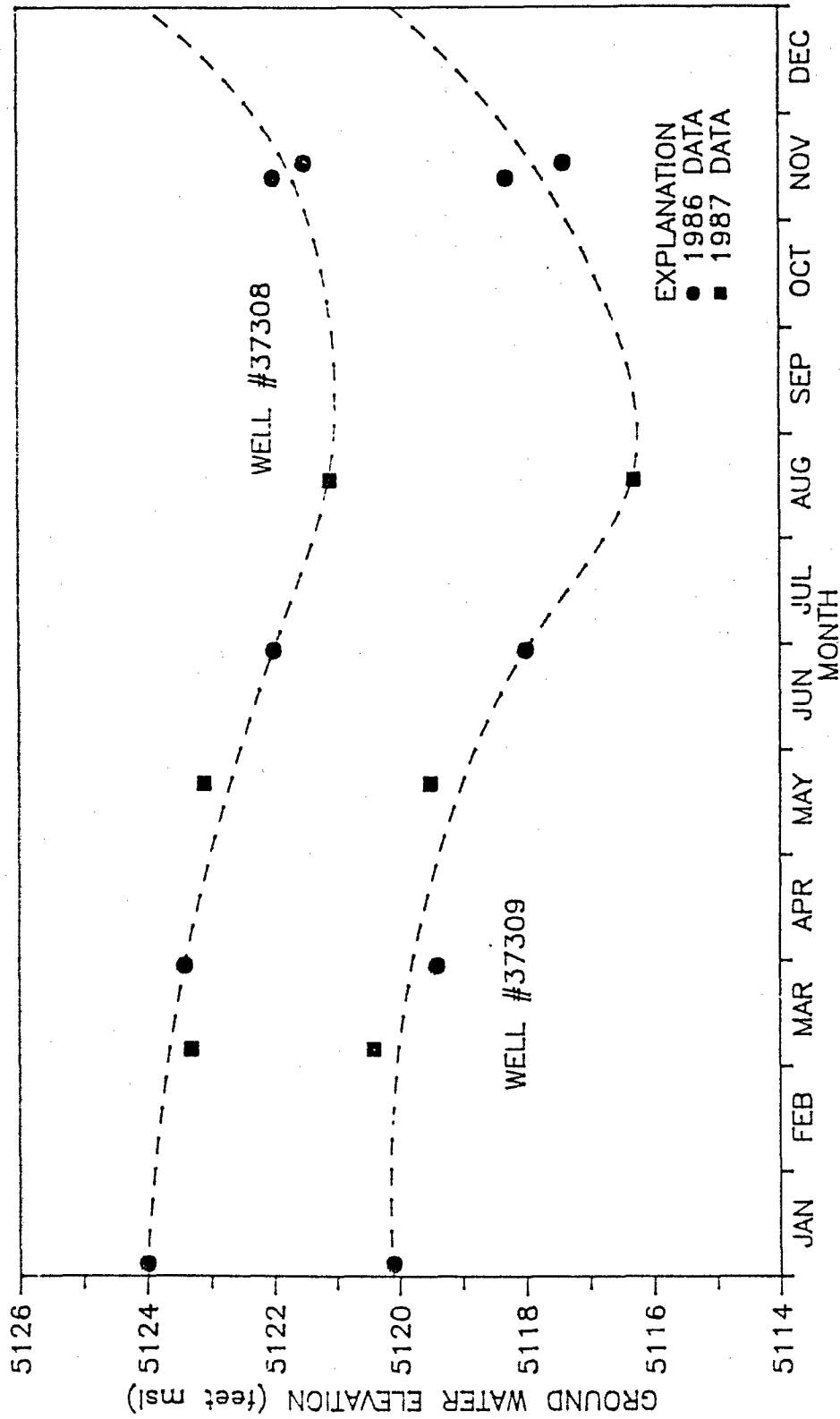


Figure 2.4-22

HYDROGRAPHIC PROFILE THROUGH NWBCS (LINE D-D')

SOURCE: Hunter/ESE, 1988

Prepared for:
 U.S. Army Program Manager's Office
 For Rocky Mountain Arsenal
 Aberdeen Proving Ground, Maryland



EXPLANATION
 ● 1986 DATA
 ■ 1987 DATA

Figure 2.4-23

SEASONAL HYDROGRAPHS FOR WELLS 37308 AND 37309

SOURCE: Hunter/ESE, 1988

Prepared for:
 U.S. Army Program Manager's Office
 For Rocky Mountain Arsenal

Aberdeen Proving Ground, Maryland

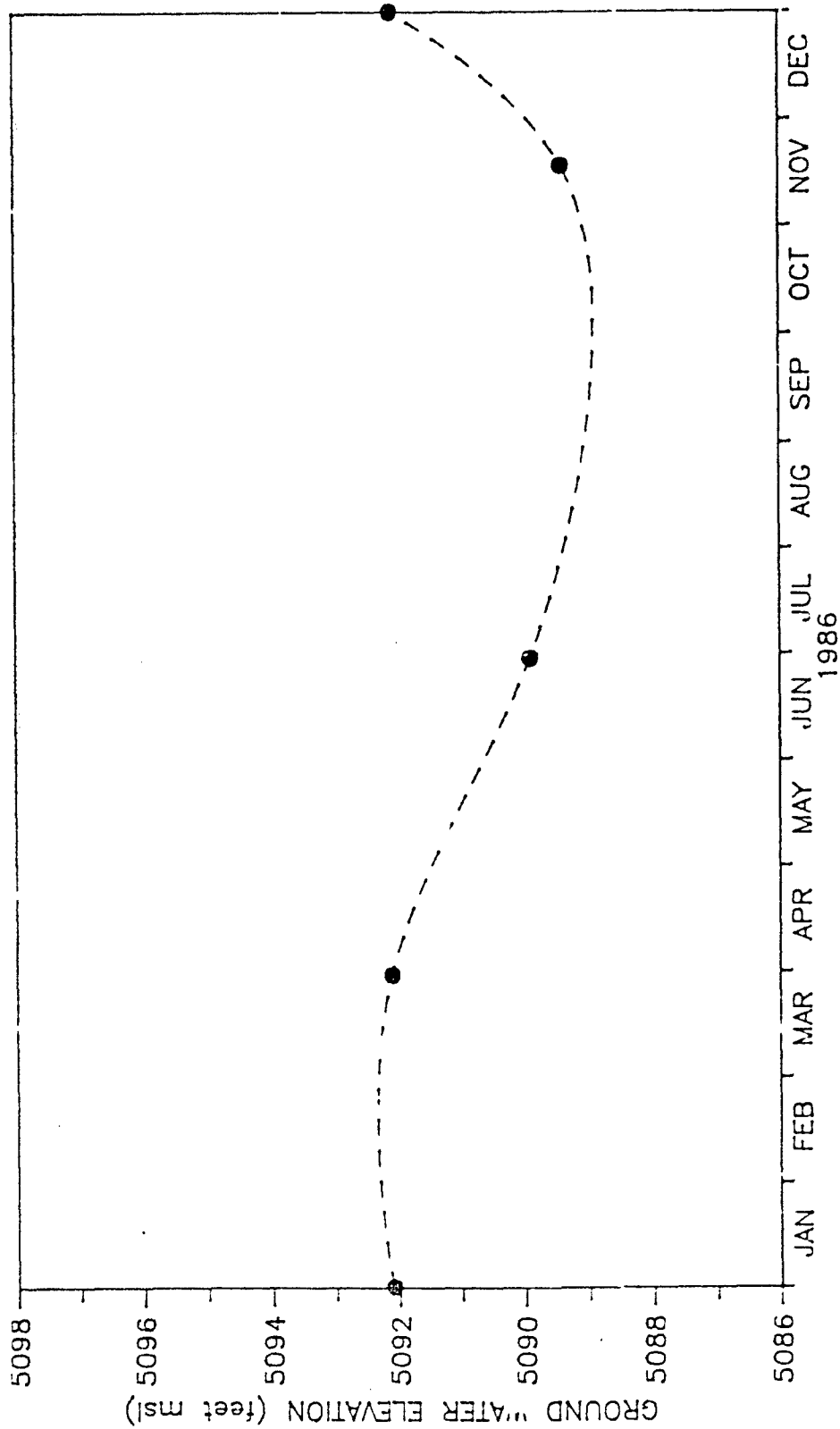


Figure 2.4-24

1986 SEASONAL HYDROGRAPH FOR WELL 37335

SOURCE: Hunter/ESE, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland

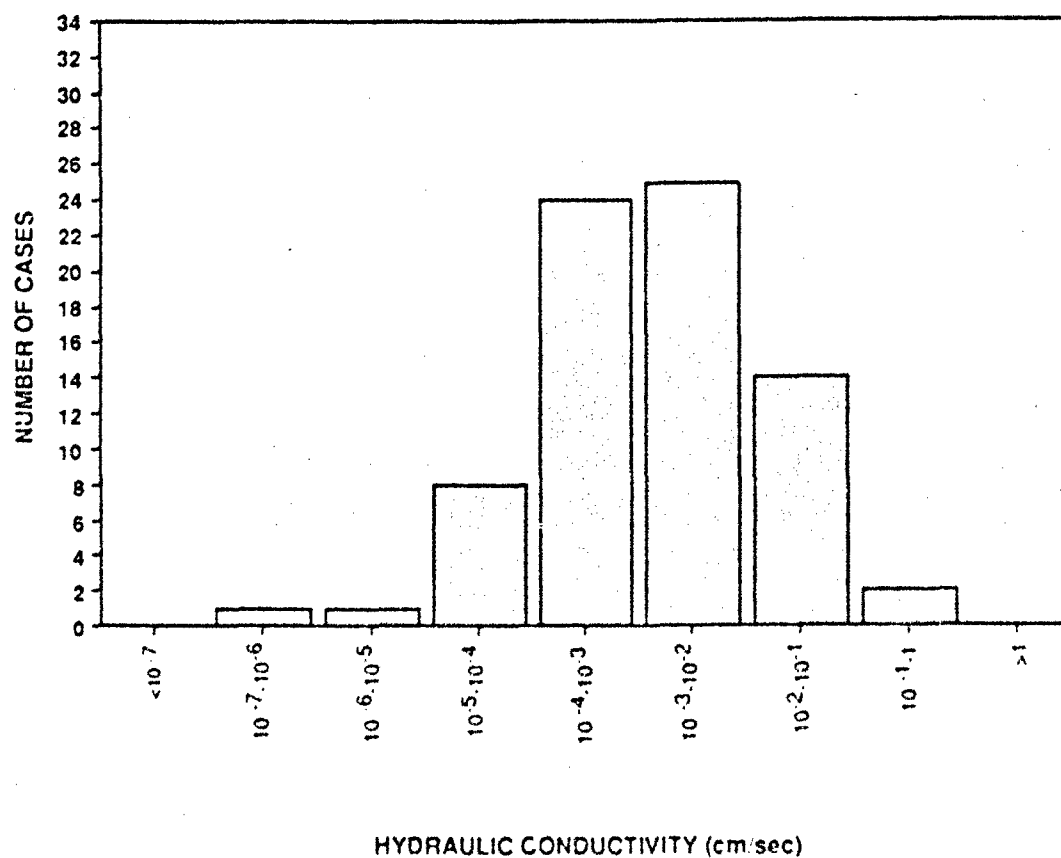
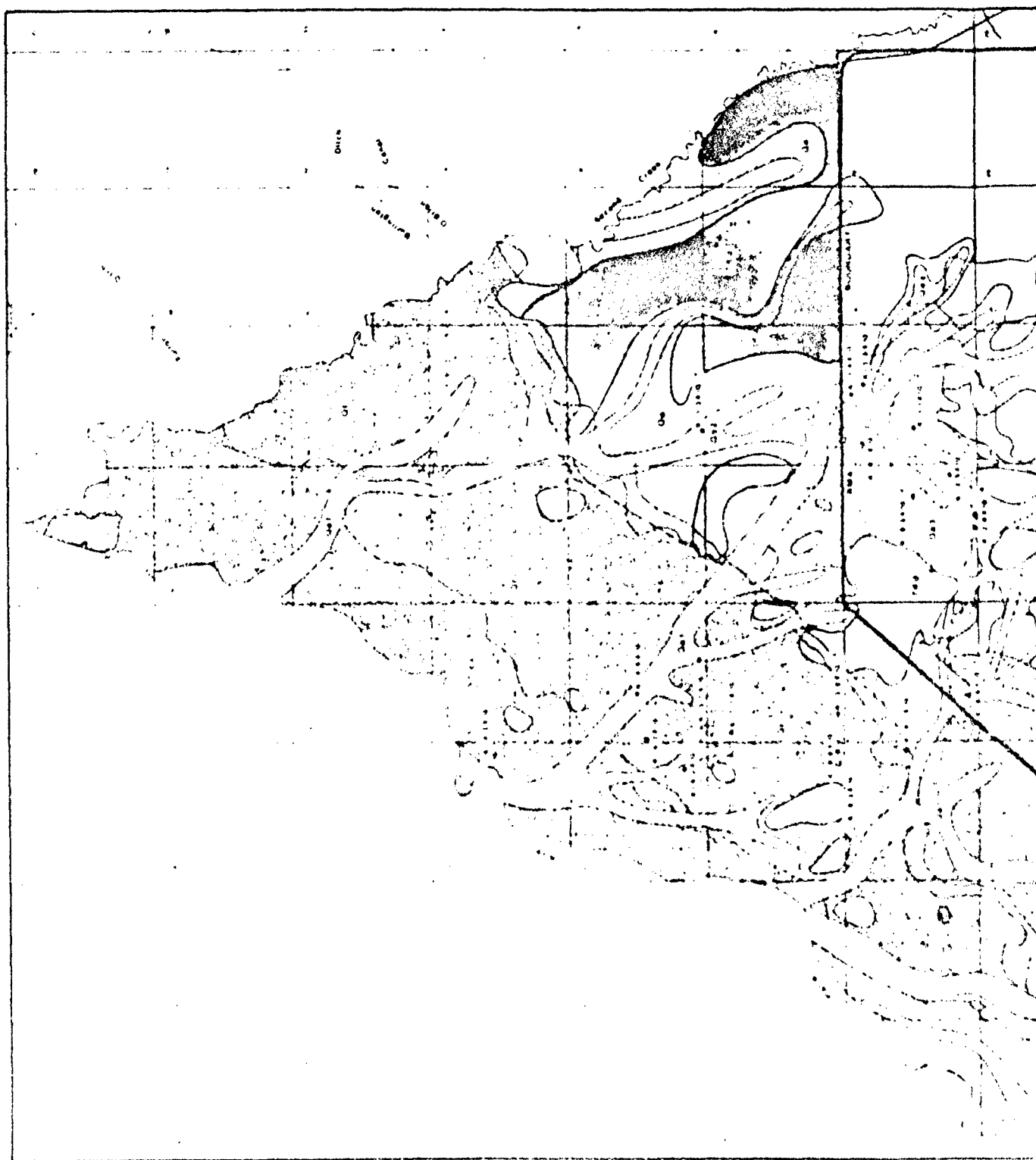


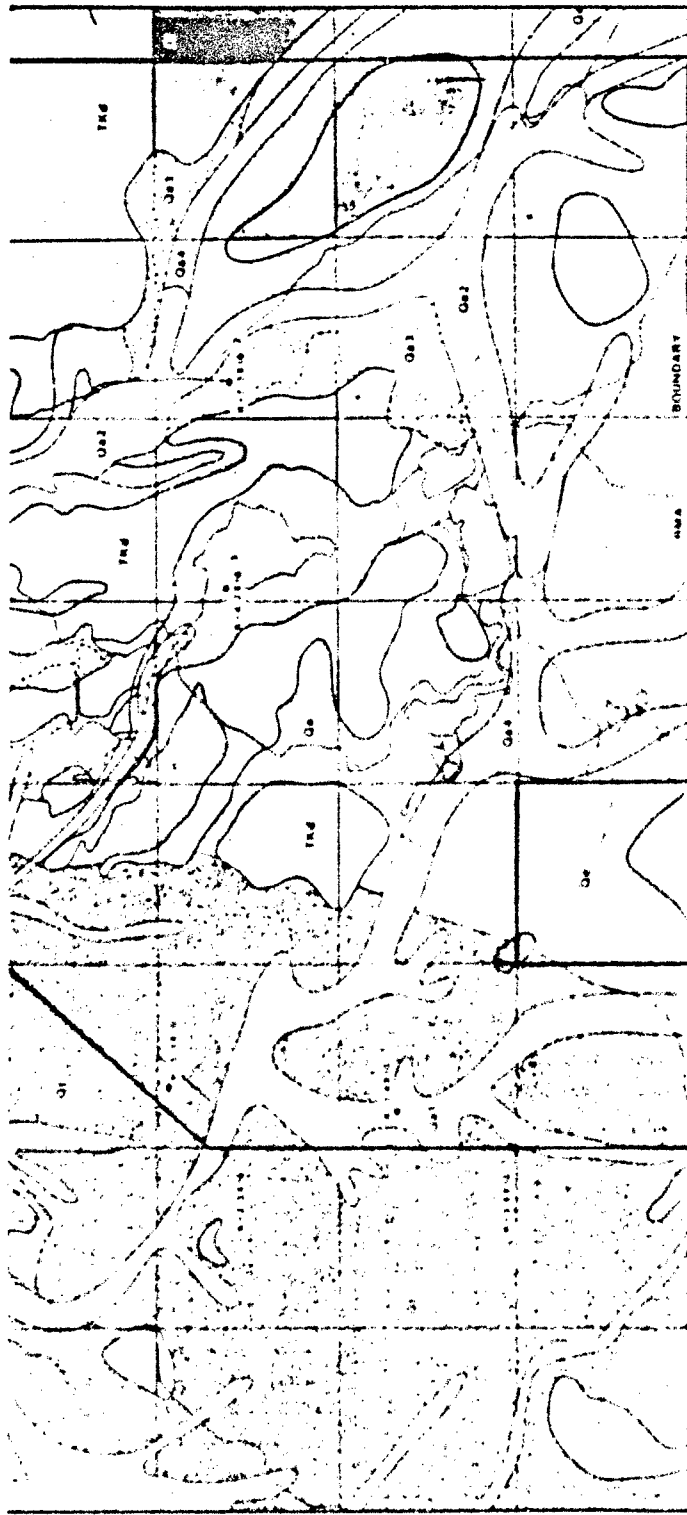
Figure 2.4-25
HYDRAULIC CONDUCTIVITY HISTOGRAM,
SLUG TESTS IN ALLUVIUM

SOURCE: Hunter/ES&I, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal

Aberdeen Proving Ground, Maryland





EXPLANATION

- Aquifer Pumping Tests
 K Value in ft/sec
- Terraces
 Paleochannels in Terrace Gravels
 Paleochannels in Eolian (w/Gravel)
- Qa1
 Qa2
 Qa3
 Qa4
 Qe
 TKd
- Silty Terrace Gravel And Coarse Sand
 Paleochannels in Eolian (w/o Gravel)
 Eolian Deposits
 Denver Fm

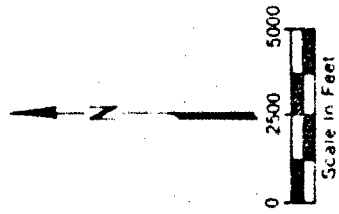
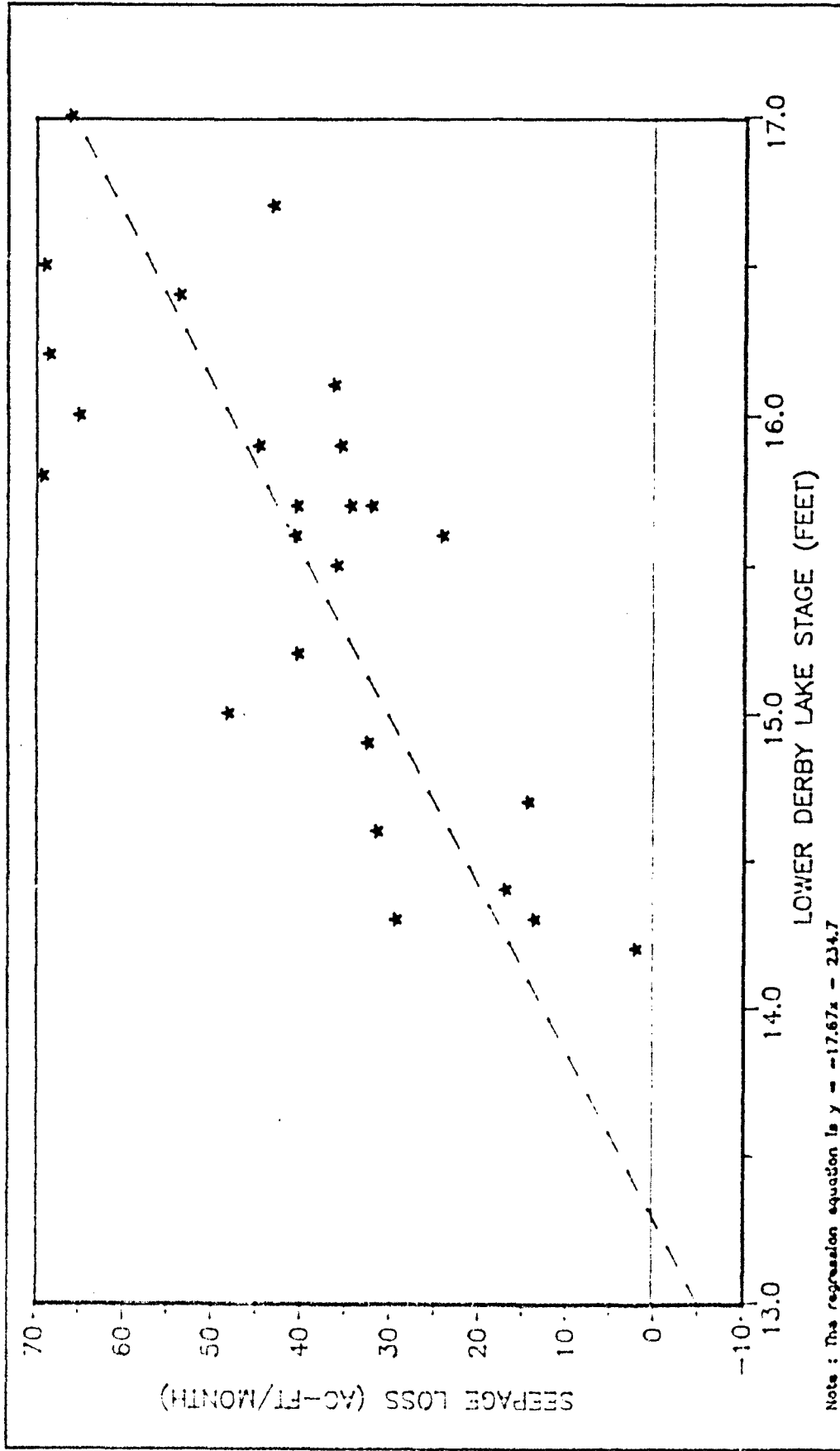


Figure 24-26
HYDROGEOLOGIC UNIT MAP FOR UNCONFINED FLOW SYSTEM

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal

Aberdeen Proving Ground, Maryland

SOURCE: MCA 1988



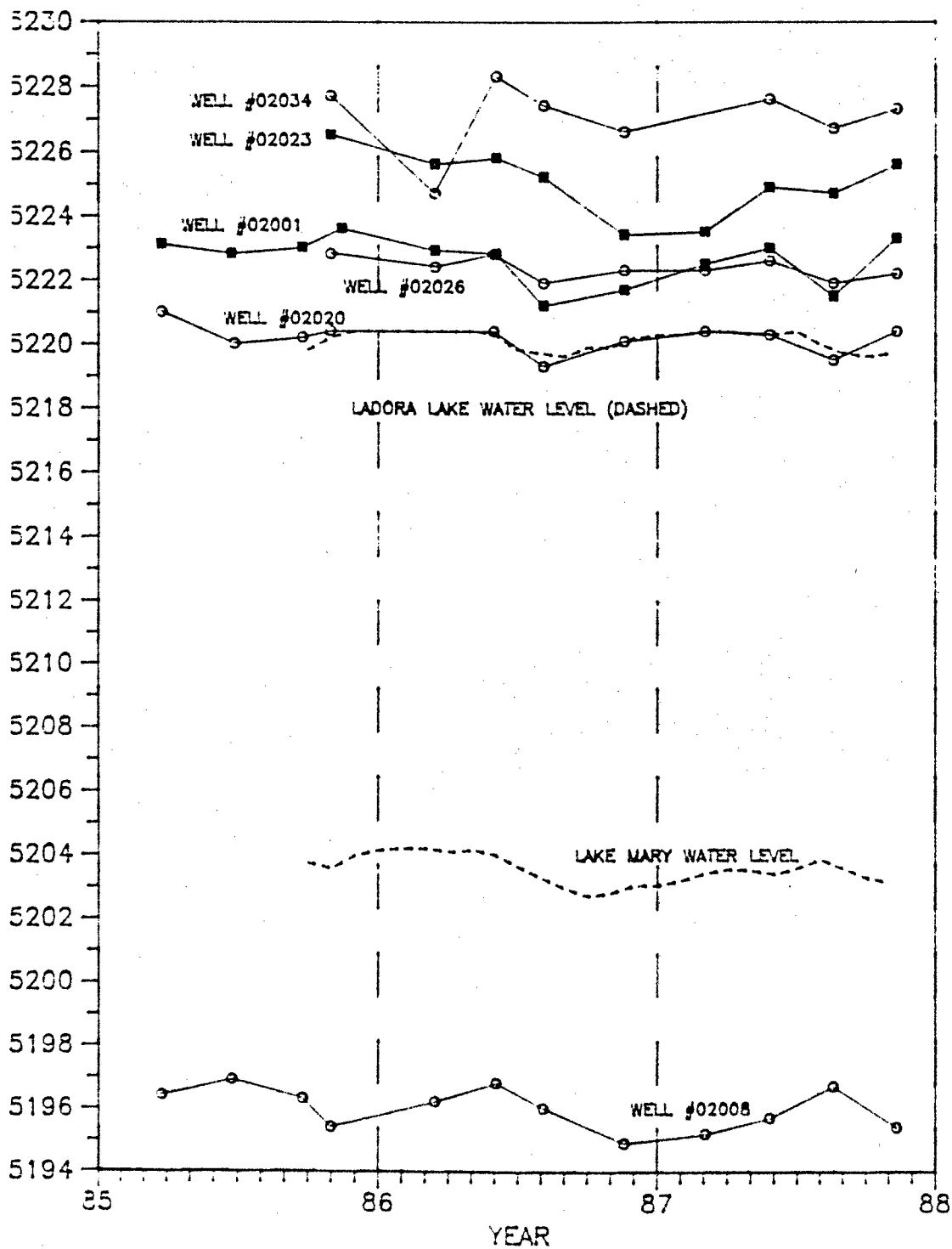
Note: The regression equation is $y = -17.67x - 234.7$

Figure 2.4-27

LOWER DERBY, LAKE STAGE LOSS RELATIONSHIP BASED ON
1986 AND 1987 MASS BALANCE CALCULATIONS

SOURCE: Hunter/FSE, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland

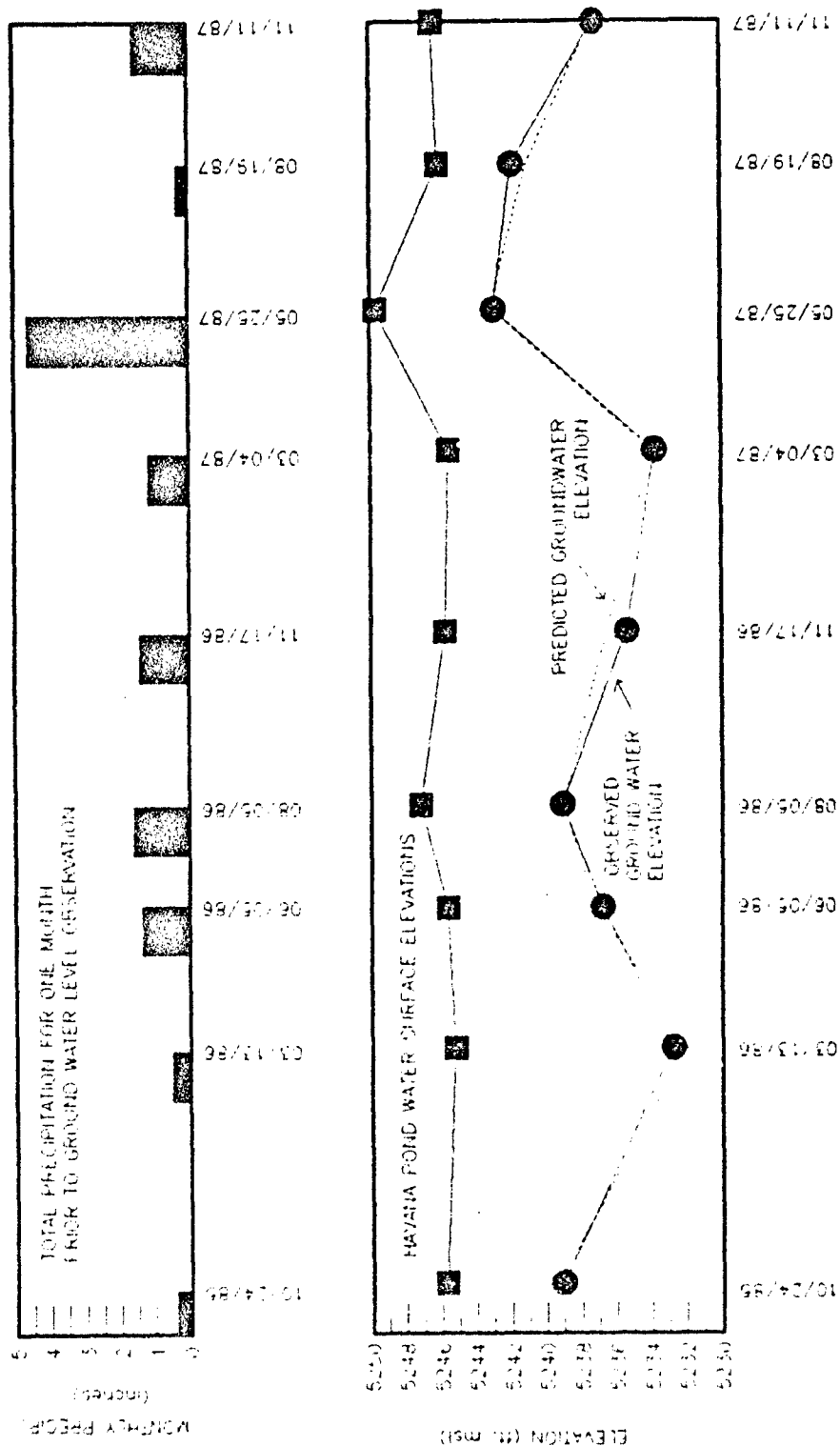


ire 2.4-28

E AND WELL LEVELS
LAKES LADORA AND MARY

CE: Hunter/ESE, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland



Note: Predicted values from regression of pond loss & surface elevation on ground water elevation

Figure 2.4-29

POND SURFACE, PREDICTED AND OBSERVED WATER TABLE ELEVATIONS WITH MONTHLY PRECIPITATION FOR HAVANA POND

SOURCE: Hunter/ESE, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland

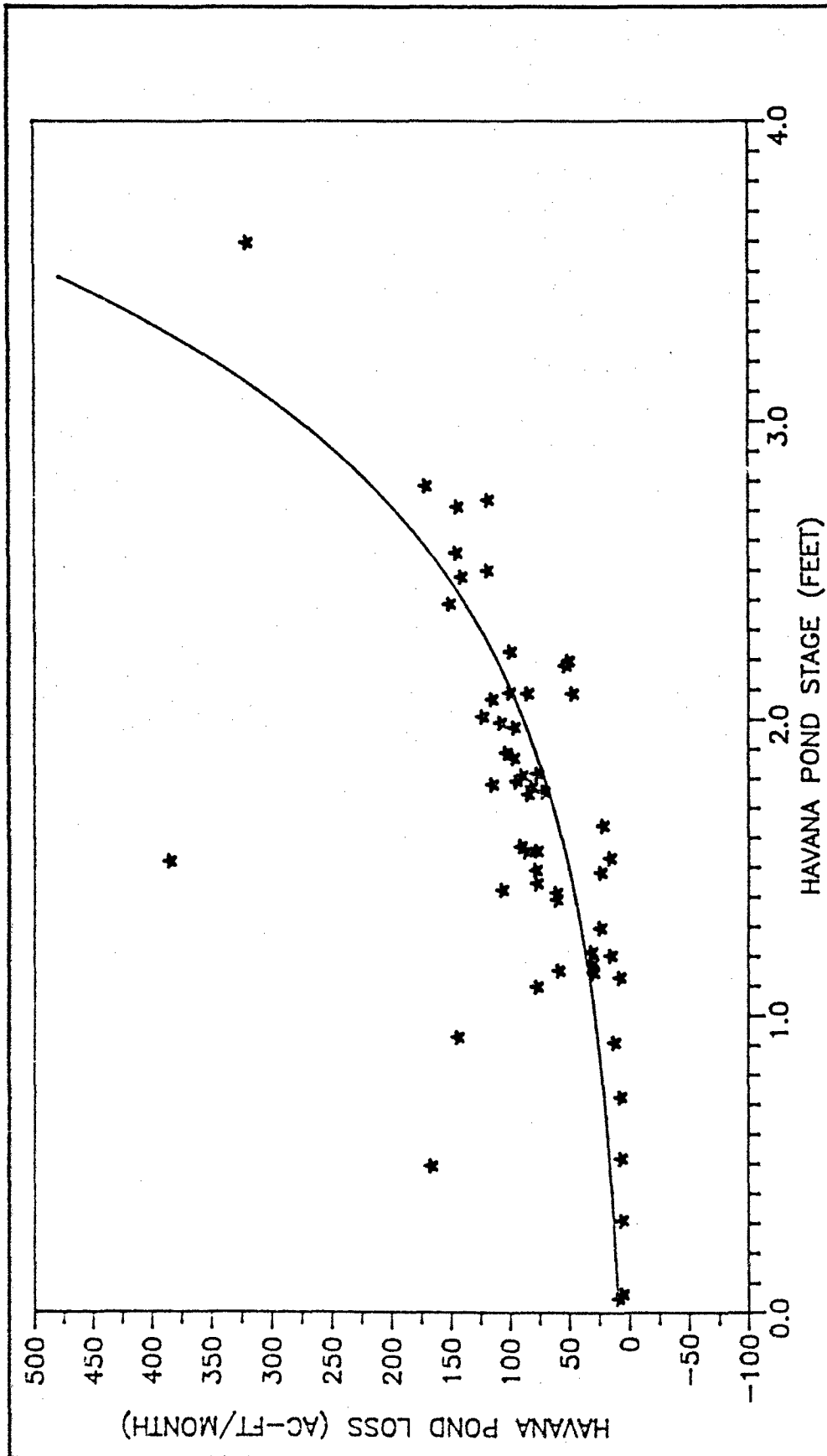
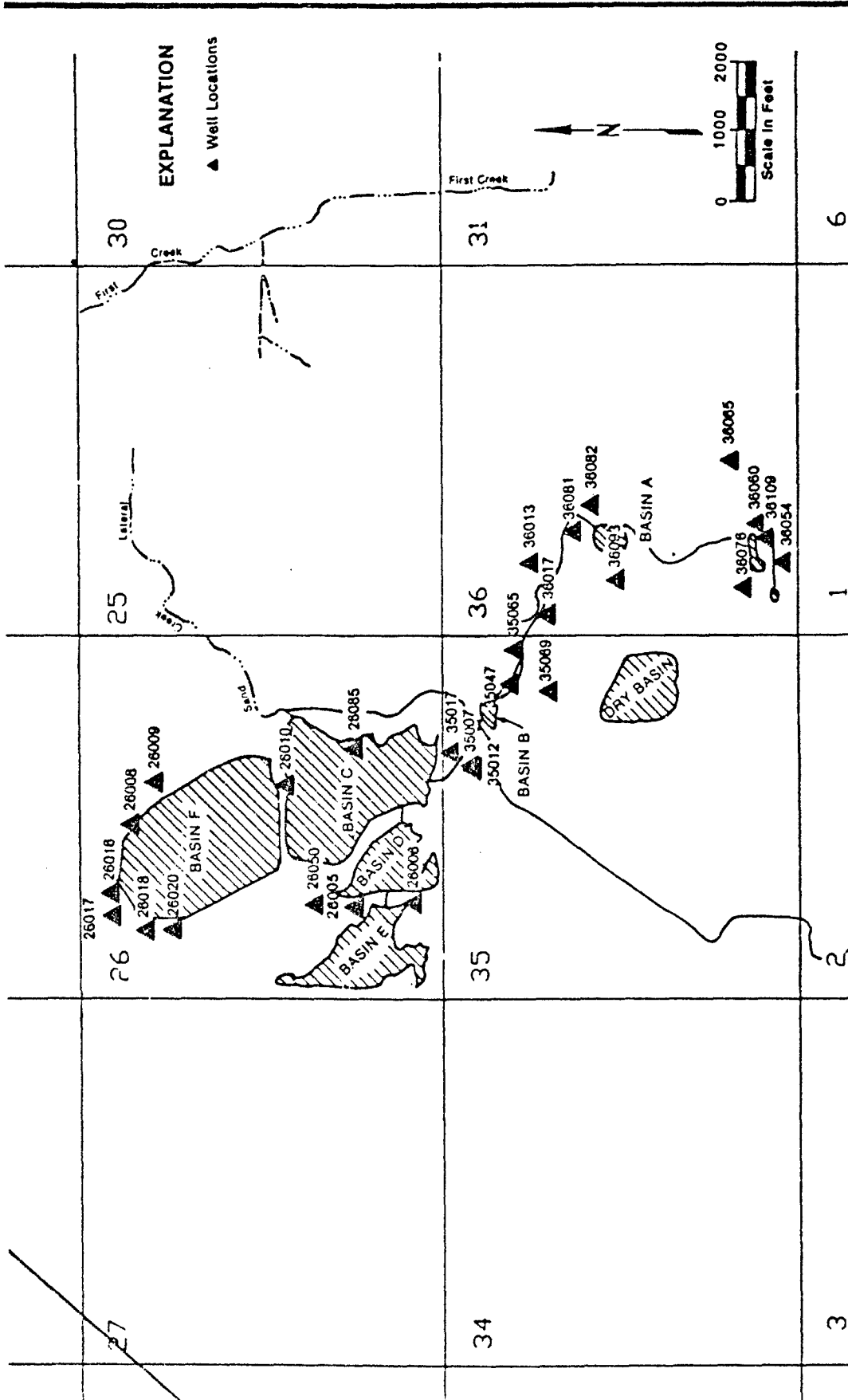


Figure 2.4-30

HAVANA POND STAGE LOSS RELATIONSHIP BASED ON 1986
WEEKLY MASS BALANCE CALCULATIONS

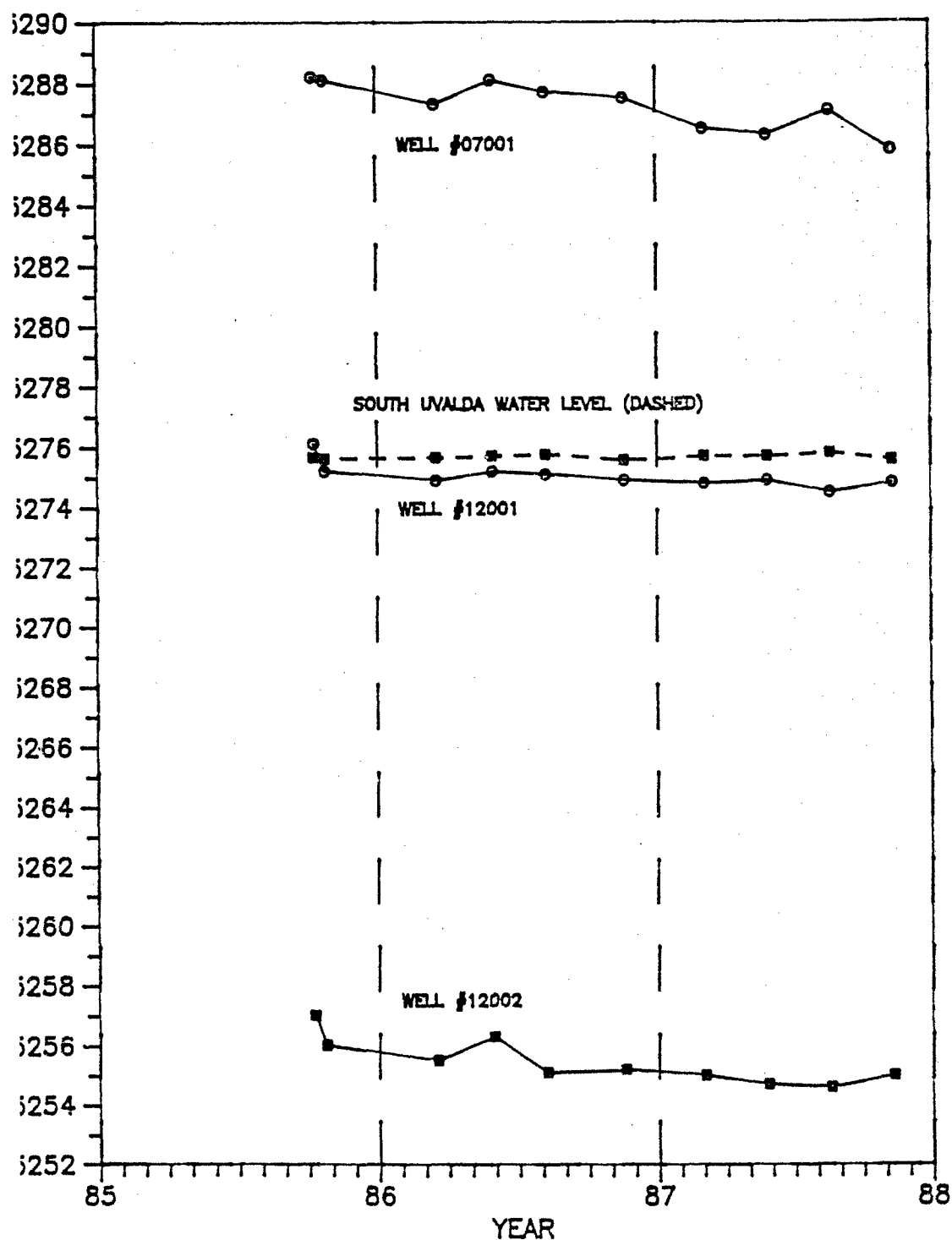
SOURCE: Hunter/ESE, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland



Prepared for:
 U.S. Army Program Manager's Office
 For Rocky Mountain Arsenal
 Aberdeen Proving Ground, Maryland

Figure 2.4-31
 BASINS LOCATION MAP
 SOURCE: Hunter/ESE, 1988

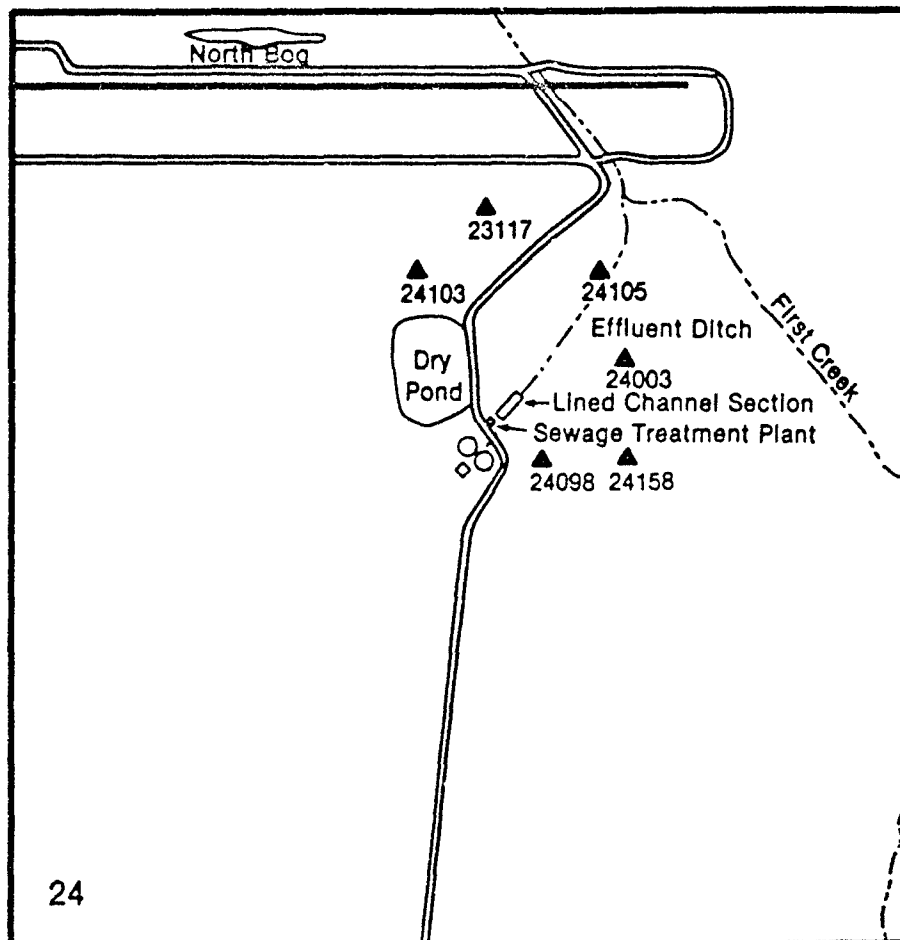


re 2.4-32

E AND WELL LEVELS BY
LDA INTERCEPTOR

DE: Hunter/ESE, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland



EXPLANATION

- ▲ Alluvial Well And Number
- Creek Or Ditch

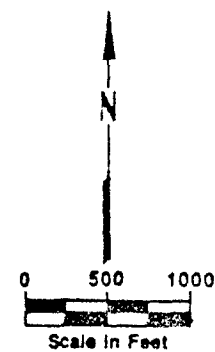
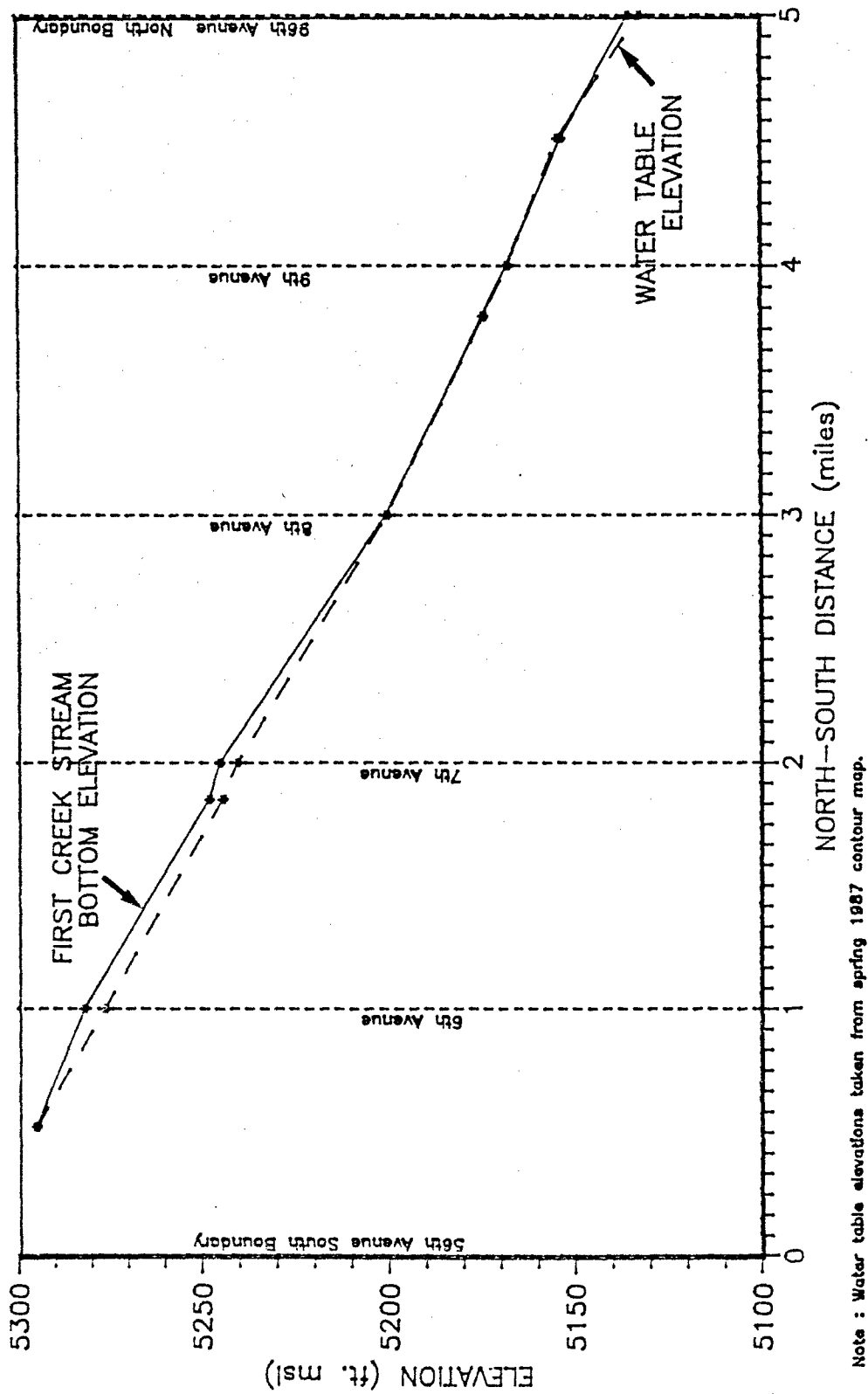


Figure 2.4-33

SEWAGE TREATMENT PLANT LOCATION AND
ASSOCIATED ALLUVIAL WELL LOCATIONS

DATE: Hunter/ESE, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland



Note : Water table elevations taken from spring 1987 contour map.

Figure 2.4-34

FIRST CREEK STREAM BED ELEVATIONS RELATIVE TO WATER TABLE ELEVATIONS

SOURCE: Hunter/ISE, 1988

Prepared for:
 U.S. Army Program Manager's Office
 For Rocky Mountain Arsenal
 Aberdeen Proving Ground, Maryland

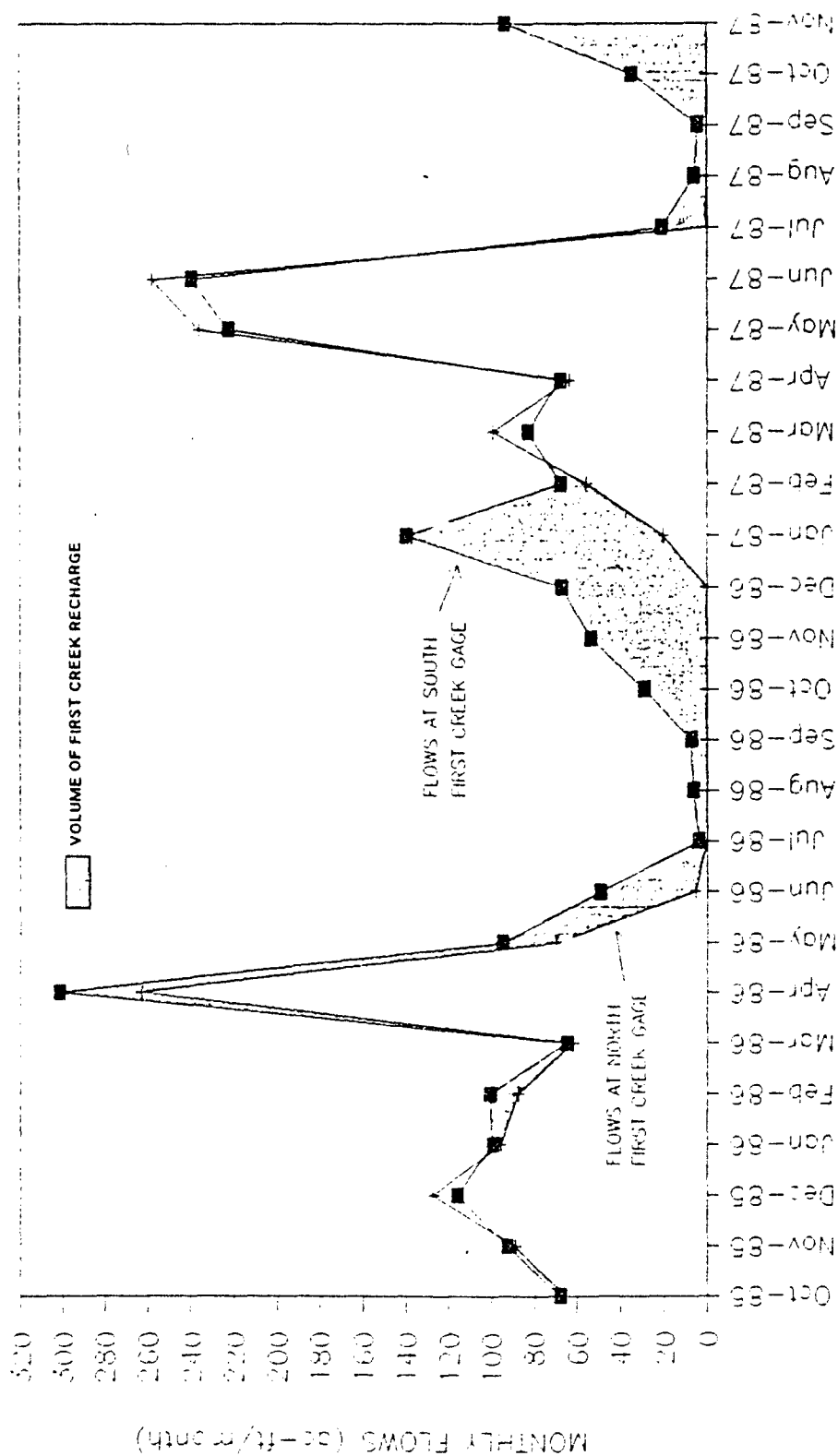
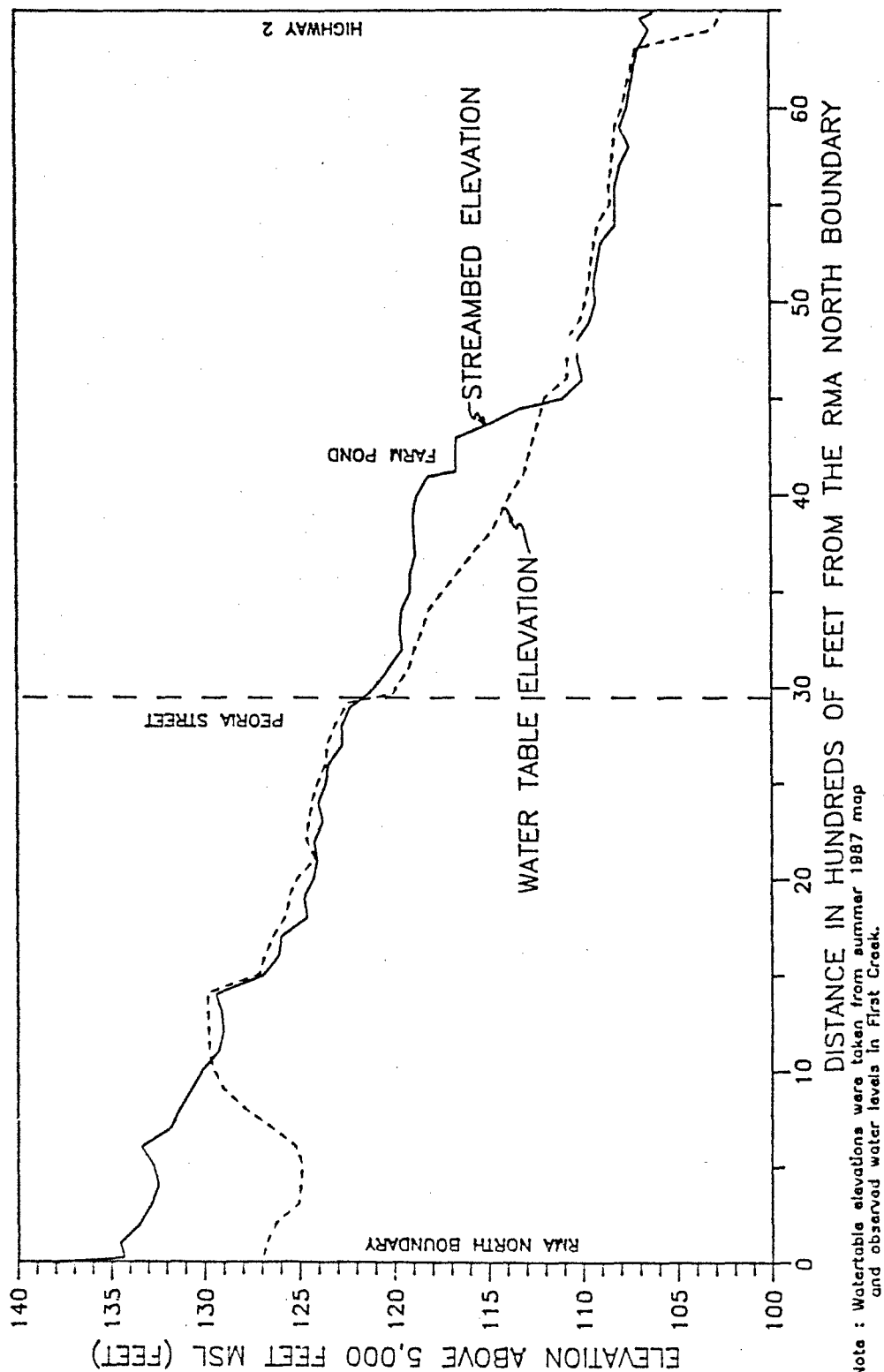


Figure 2.4-35

COMPARISON OF FIRST CREEK FLOWS AT THE NORTH AND SOUTH GAGES

SOURCE: Hunter/ESE, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland



Note: Watertable elevations were taken from summer 1987 map and observed water levels in First Creek.

Figure 2.4-36

ESTIMATED GROUND WATER ELEVATIONS ALONG FIRST CREEK FROM THE RMA NORTH BOUNDARY TO HIGHWAY 2

SOURCE: Hunter/ESE, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland

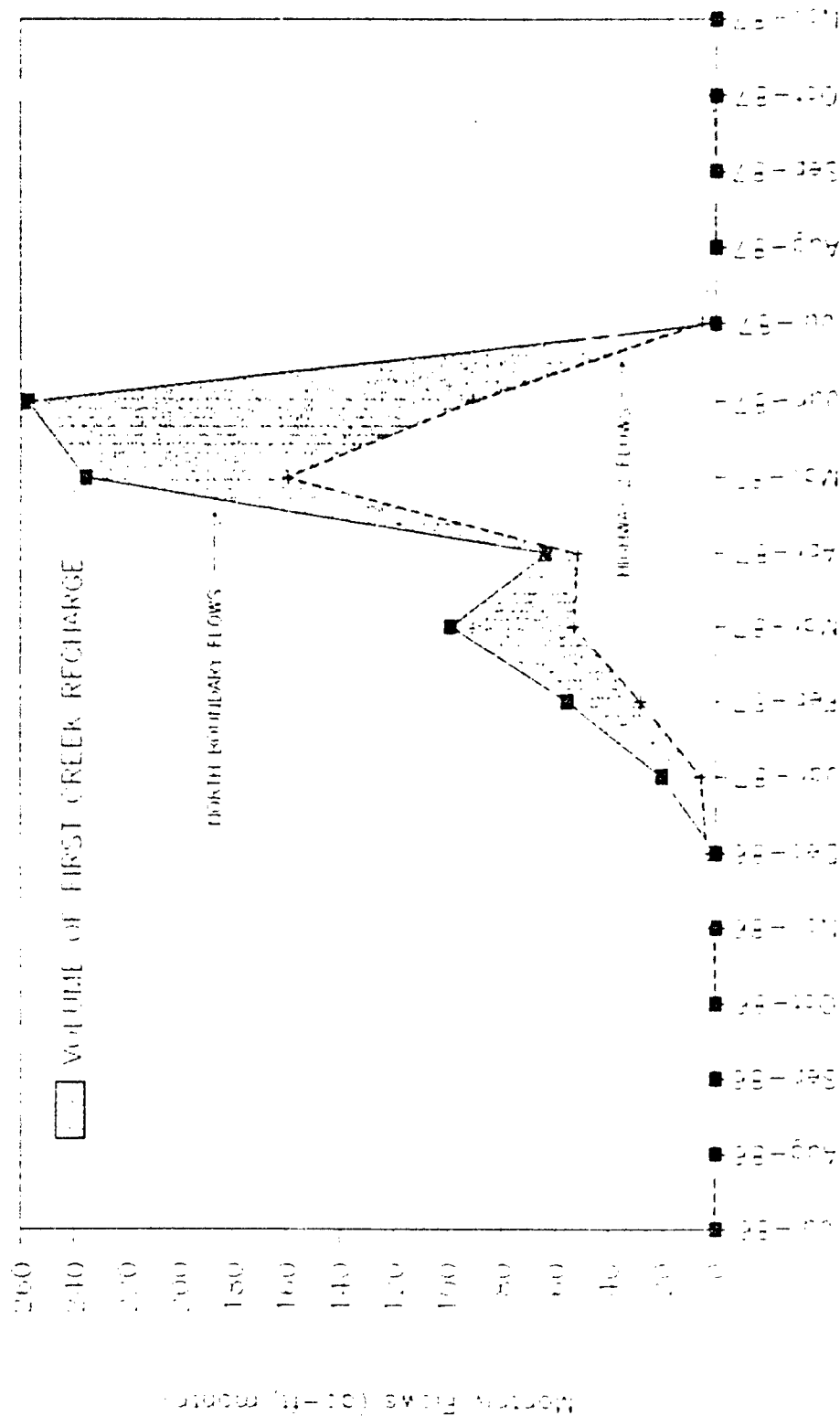


Figure 2.4-37

COMPARISON OF FIRST CREEK FLOWS AT RMA NORTH
BOUNDARY AND HIGHWAY 2

SOURCE: Hunter/LSE, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland

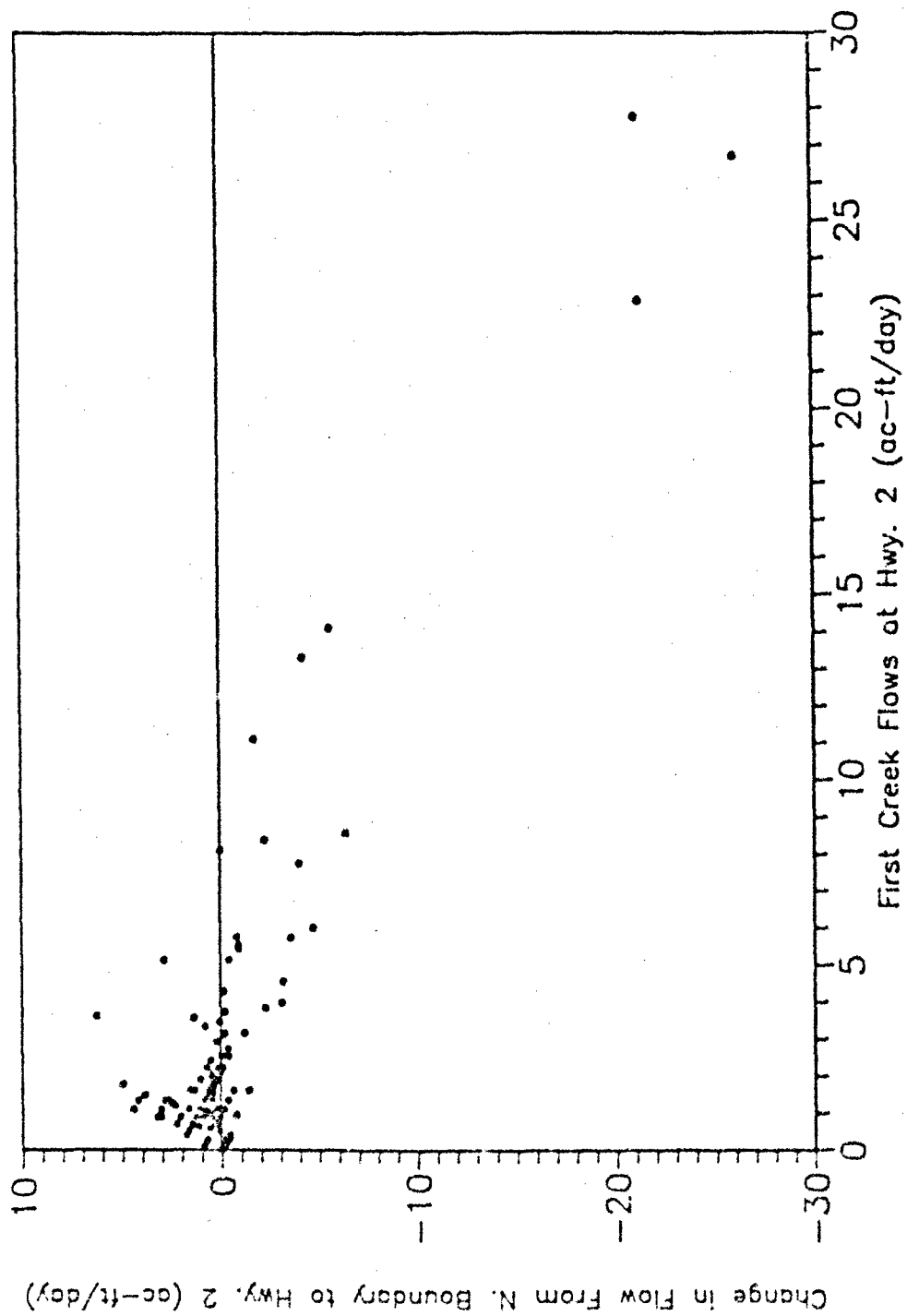


Figure 2.4-38

CHANGE IN FIRST CREEK FLOWS OFFPOST VS. DISCHARGE AT
HIGHWAY 2 STATION

SOURCE: HunterESE, 1968

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland

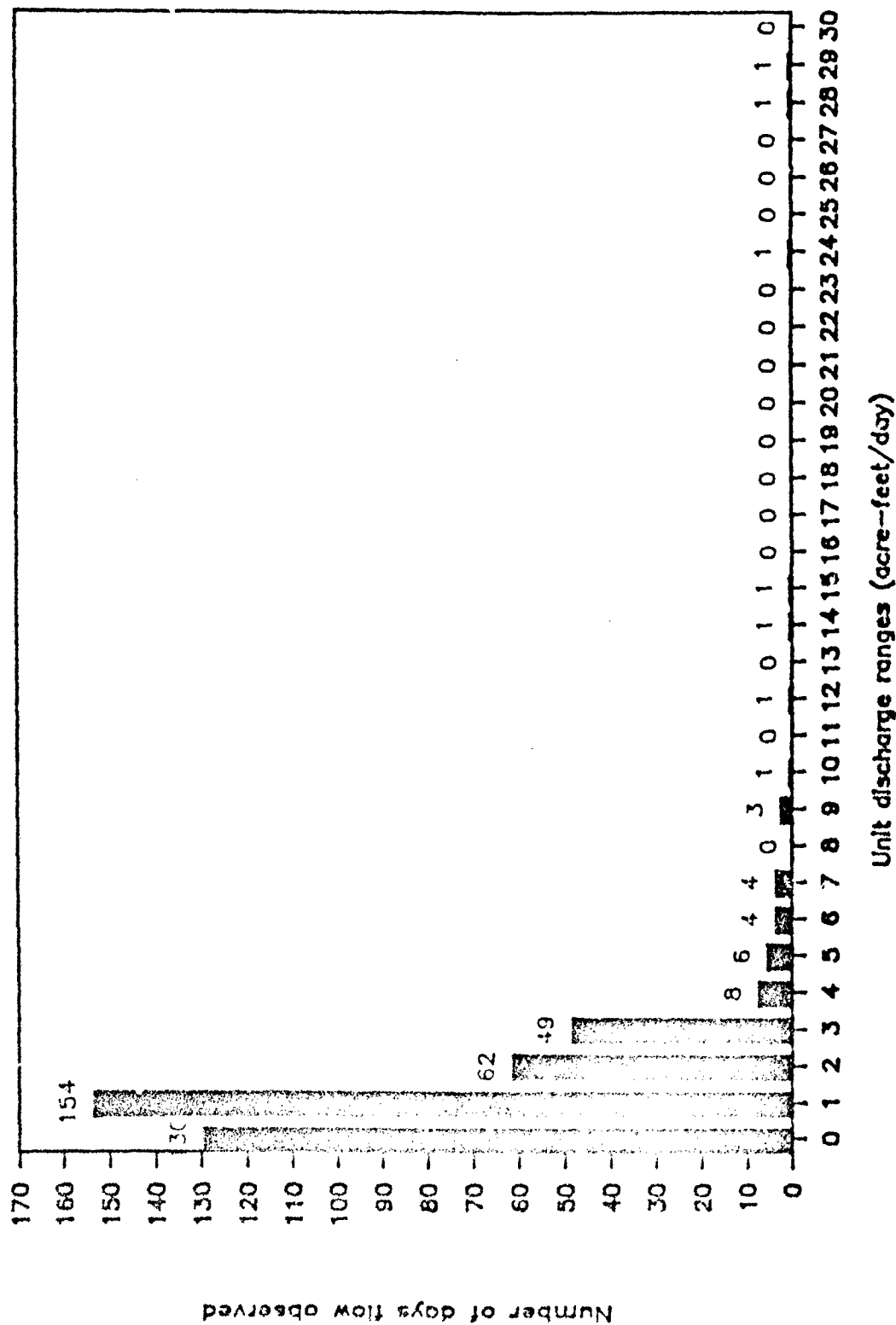


Figure 2.4-39

FLOW FREQUENCY HISTOGRAM FOR FIRST CREEK AT HIGHWAY
2 STATION (JULY 1986 THROUGH AUGUST 1987)

SOURCE: HUSTON ESE 1342

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland

3.0 SAMPLING AND ANALYSIS PROGRAMS AT RMA

The purpose of this section is to discuss the historical groundwater sampling and analytical programs that have been conducted to date under various RMA efforts and to summarize the more recent sampling and analysis programs.

The following discussion summarizes methods of investigation, sampling programs and analytical programs that were followed by both historic and more recent RMA groundwater investigations. Overall objectives of these programs are discussed in Section 1.0, and detailed discussions of task objectives may be found in the individual task reports. Detailed assessments of specific sampling and analytical programs are also included in individual task reports.

The Water Remedial Investigation evolved from Tasks 4 and 44 which were the initial tasks designated to provide a comprehensive overview of groundwater/surface water contamination at RMA. Well installation, development, network selection, sampling and analyses conducted under Task 44 are discussed in Appendix C.

3.1 Methods of Investigation

A significant effort has been devoted to monitoring RMA groundwater quality over the past 12 years using the approximately 2,000 monitoring wells that have been installed both on-post and off-post under various programs (Plate 19). The rationale used to select groundwater monitoring networks for recent RMA tasks was based on the different task objectives (Section 1.0). Monitoring well network selection rationale for Tasks 4, 25, 36, 38 and 39 are included in individual task reports, and selection rationale for the Task 44 network is included in Appendix C.

Recent efforts of various Remedial Investigation Tasks included proposed installation of new wells. The Composite Well Program was established under Task 44 to monitor these activities and prevent duplication of well installations. The Composite Well Program evaluated task-specific objectives to ensure that task requirements were fulfilled by the new well installations. It also attempted to fill data gaps in the regional scheme.

The locations of Composite Well Program wells, well selection rationale, status and the

task under which wells were installed are discussed in the Composite Well Program Draft Final Report (ESE, 1988b, RIC#88244R02). A total of 148 wells were installed from Fall 1986 to Spring 1988 as part of the Composite Well Program. Available data representative of an appropriate sampling period were included in Water Remedial Investigation Report assessments.

3.2 Sampling Programs

Numerous RMA programs have incorporated groundwater sampling to fulfill specific program or task objectives. Since 1985, over 1,900 groundwater and surface water samples have been collected under a number of programs and have contributed to an extensive groundwater quality database that has been compiled through Data Base Management System (DBMS).

The study areas of recent Remedial Investigation groundwater tasks are shown in Figure 1.4-2, which illustrates the overlapping nature of many of the more recent RMA tasks. This more recent, task-integrated effort provided the comprehensive database from which Water Remedial Investigation interpretations were generated, although historic efforts provided essential background for these interpretations. The specific sampling networks and data used to generate the water quality interpretations that are included in this report are discussed in Section 4.0.

3.2.1 Historical Sampling Programs

The historical groundwater monitoring effort has included several major monitoring programs designed to accomplish a variety of objectives (Section 1.0). These programs include the 360° Monitoring Program, the Basin F Monitoring Program, North and Northwest Boundary Containment System monitoring, Irondale Boundary Control System monitoring and the U.S. Engineer Waterways Experiment Station Regional Monitoring Program.

3.2.1.1 360° Monitoring Program

The 360° Monitoring Program was initiated in 1976 to provide both RMA-wide monitoring and off-post monitoring of groundwater quality. The initial program included the sampling

of 55 onsite wells and 20 offsite wells, plus 12 onsite surface water locations and 10 offsite surface water locations. Quarterly sampling was conducted onsite by RMA personnel and coordinated offsite by the Tri-County Health Department (Ward, 1984, RIC#84088R01).

Since its initiation, there have been numerous changes in the program in response to changing groundwater contamination patterns and problems related to groundwater quality. In 1976, Revision II added approximately 55 groundwater wells to the 360° Program, including many wells located north and northwest of the RMA boundary. In 1985, Revision III of the 360° Program was implemented and included 43 off-post wells (ESE, 1986, RIC#87016R05). Sampling of 43 wells on-post and off-post and 11 surface water locations that were originally conducted under the 360° program was conducted by Task 44 on a quarterly basis.

3.2.1.2 Basin F Monitoring Program

The Basin F Monitoring Program was initiated to evaluate potential leakage from Basin F. Six groundwater monitoring wells were first installed in 1969, with four additional wells installed in 1975. Quarterly monitoring of these wells occurred from 1975 to 1985, and additional wells have been installed in this area since 1975. Monitoring of this site was incorporated in 1985 with the Task 4 network and was incorporated under Task 44.

3.2.1.3 North and Northwest Boundary Systems Monitoring

Monitoring of the North Boundary Containment System and the Northwest Boundary Containment System was initiated in 1978 and 1981, respectively, to assess the effectiveness of these containment systems. Initially, 54 wells from the North Boundary Containment System and 17 wells near the Northwest Boundary Containment System were sampled, although these networks were increased to 80 wells near the North Boundary Containment System and 45 wells near the Northwest Boundary Containment System. Specific sampling networks are included in the North and Northwest Boundary Reports. Groundwater sampling was conducted on at least a quarterly basis. More recently, Task 25 was initiated to assess groundwater contamination in these areas, and Task 36 was assigned to evaluate the effectiveness of the North Boundary Containment System.

3.2.1.4 Irondale Boundary Control System Monitoring

The Irondale Boundary Control System was established in December of 1981 to mitigate DBCP exiting RMA near the Irondale Boundary Control System. Approximately 58 wells were sampled on a quarterly basis between 1981 and 1986 in the area. Analyses for DBCP only were conducted on samples collected in this program. Evaluation Reports were written (RIC#82350R03, RIC#84065R01, RIC#85130R01, RIC#88195R01) that summarize sampling results and effectiveness of the boundary system.

3.2.1.5 U.S. Engineer Waterways Experiment Station Regional Monitoring Program

A regional groundwater sampling program was initiated by U.S. Engineer Waterways Experiment Station in 1980. Approximately 245 wells were sampled between 1980 and 1983. Samples were collected from four on-post areas referred to as the Northwest Boundary, South Plants, Basin A Neck and Eastern Arsenal (Spaine, et al., 1984, RIC#85133R04).

3.2.2 Recent Sampling Programs

Groundwater monitoring programs established since 1985 have included both regional and site-specific monitoring which was conducted under numerous tasks. Data and interpretation from these tasks provided the bulk of the information used for interpretations conducted under the Water Remedial Investigation efforts. Table 3.2-1 summarizes sampling period, frequency, number of wells sampled, number of new wells installed under the Composite Well Program and number of surface water sampling sites for each task. Specific sampling procedures used during these programs are included in individual task reports. These procedures are essentially identical for each task, therefore Task 44 procedures presented in Appendix C are representative of Remedial Investigation sampling protocols.

Table 3.2-1 Summary of 1985 to 1987 RMA Sampling Programs

Task	Sampling Period	Sampling Frequency	Number of Wells Sampled	Number of CWP ¹ Wells Installed ⁵	Number of Surface-Water Stations Sampled
4 ³	ISP ² : October 1985 to March 1986	Single Event	178 - Alluvial 143 - Denver	0	25
	3rd & 4th Quarter: April to September 1986	Quarterly ⁴	3rd: 100 Alluvial, 80 Denver; 4th: 99 Alluvial, 83 Denver	0	3rd: 19 4th: 21
25	September 1986 to December 1987	Quarterly	91 Alluvial ⁶ 26 Denver ⁶	10	0
36	June 1987 to October 1987	Quarterly	67 Alluvial ⁶ 30 Denver ⁶	18	0
38	December 1986 to September 1987	Quarterly	52 Alluvial ⁶ 0 Denver ⁶	31	0
39	June 1987 to October 1987	Quarterly	57 Alluvial ⁶ 16 Denver ⁶	15	11
44	September 1986 to March 1987	Quarterly	54 Alluvial 1 Denver	22	41
	April 1987 to June 1987	Single Event	Proposed: 170 Alluvial 141 Denver		37
	July 1987 to September 1987	Single Event	54 Alluvial 1 Denver	22	27

1 Initial Screening Program

2 Composite Well Program

3 3rd & 4th Quarter report contained an additional 43 off-post wells and 11 off-post samples during the 4th Quarter in the 360° Monitoring program; numbers not included in well totals.

4 Quarters by 3 month increments, with October to December = one quarter, etc.

5 Additional wells completed under soils tasks included in the Composite Well Program Report (ESE, 1988e).

6 Number of wells sampled in spring 1987; reader is referred to task reports for wells sampled under additional quarters.

Source: ESE, 1988.

3.2.2.1 Task 4 RMA Water Quantity/Quality Survey

Task 4 was a regional groundwater monitoring program conducted on the RMA on-post area between October 1985 and September 1986. It included an initial sampling of 320 on-post wells between October 1985 and March 1986 and two additional quarters of sampling (April through June 1986 and July through September 1986) of 188 wells/quarter.

Analytical and hydrologic data acquired in the initial sampling period were presented in the Initial Screening Program Report and results from the Third and Fourth Quarter efforts were presented in the Final Screening Program Report. Regional sampling after September 1986 was assumed under Task 44. Specific sampling networks for each quarter are discussed in the Final Initial Screening Program Report (ESE, 1987a, RIC#87253R01) and the Final Screening Program Report (ESE, 1988a, RIC#88173R06).

3.2.2.2 Task 25 - North and Northwest Boundary System Monitoring

Task 25 was initiated to collect data to assess the effectiveness of the North Boundary Containment System and Northwest Boundary Containment System. This task included quarterly sampling of alluvial and Denver Formation wells from September 1986 to December 1987, although wells sampled under Tasks 44, 36 and 39 within the Task 25 study area were included in the assessment. In addition to quarterly sampling of wells upgradient and downgradient of the boundary systems, an additional 260 samples were taken quarterly from the treatment plants. Ten new wells were installed under this task. The specific quarterly sampling networks are included in the Draft Final Task 25 Report (ESE, 1988f, RIC#89024R02).

3.2.2.3 Task 36 - North Boundary System Component Remedial Action Assessment

Task 36 was issued to evaluate the effectiveness of the North Boundary Containment System. This task included the sampling of 67 alluvial and 30 Denver Formation wells. These wells were sampled on a quarterly basis from June 1987 to October 1987. Eighteen new wells and 10 piezometers were installed under this task. The Task 36 groundwater sampling network is discussed in the Task 36 Final Report (ESE, 1988e, RIC#88344R02).

3.2.2.4 Task 38 - Western Tier Trichloroethylene Investigation

Task 38 was issued to investigate the trichloroethylene groundwater plume that occurs along the Western Tier of RMA. Quarterly sampling of 52 wells was conducted from December 1986 through September 1987, and 31 new wells were installed under this task. The Task 38 groundwater sampling network is included in the forthcoming Western SAR.

3.2.2.5 Task 39 - Off-post Remedial Investigation

The objectives of Task 39 were to complete groundwater Remedial Investigation work initiated under the Off-post Contamination Assessment Draft Final Report (ESE, 1987c, RIC#88343R01). Under this task, 50 off-post groundwater samples were collected on a quarterly basis from June 1987 to October 1987, and 15 new groundwater monitoring wells were installed. The Task 39 sampling network and results of this assessment are included in the RI/FS Off-Post Final Report (ESE, 1989b, RIC#89024R01). Miscellaneous programs with site specific monitoring include Task 42 - North Plants and Task 11 - Hydrazine Facility.

3.2.2.6 Task 44 - Regional Groundwater Monitoring

Task 44 was initiated to provide a comprehensive integration of on-post and off-post groundwater investigations and to provide regional groundwater monitoring. Data collection for the task included installation of 22 wells, quarterly sampling of 43 off-post wells from September 1986 to March 1987, quarterly sampling of 41 on-post and off-post surface water sites from September 1986 to March 1987, and a single sampling event of 311 on-post wells from April to June 1987. The Task 44 sampling network and analytical results are presented in Appendix C.

3.2.2.7 Shell South Plants Monitoring Program

The Shell South Plants Monitoring Program was performed to gather water quality data from the Unconfined Flow System in South Plants. This monitoring program was undertaken between February 1988 and April 1988. Ninety-five wells were sampled and all the standard analytes were analyzed.

3.3 Analytical Programs

The number and types of contaminants included in recent analytical programs has grown markedly from early monitoring programs. Programs of the 1950's analyzed for only chloride, fluoride and unspecified herbicidal chemicals (Wingfield, 1977, RIC#81266R68). With the identification of diisopropylmethyl phosphonate and DBCP in surface water moving off-post in 1976, these compounds as well as aldrin, dieldrin, endrin, isodrin, dithiane, oxathiane, chlorophenylmethyl sulfide, chlorophenylmethyl sulfoxide and chlorophenylmethyl sulfone were added to the target analyte list for the 360° Monitoring Program. Investigations conducted during the early 1980's identified the presence of volatile organic compounds in the RMA groundwater including toluene, xylene, benzene, chlorobenzene, chloroform, methylene chloride, carbon tetrachloride, dichloroethylene, trichloroethylene and tetrachloroethylene (Spaine *et al.*, 1984, RIC#85133R04). These compounds were added to the target analyte list for the latest RMA programs.

The analytical programs for Tasks 25, 36, 39 and 44 include the most extensive list of target analytes to date. The objectives of these chemical analysis programs were to provide Program Managers Office RMA (PMO-RMA) with reliable, statistically supportable, and legally defensible chemical data regarding type and level of contamination in surface and groundwater at RMA. The investigation required various analytical techniques to be performed, in order to achieve a quantitative determination of water quality for collected samples. GC/MS confirmation of analytes, identified by quantitative methods and a GC/MS identification of nontarget and unknown compounds, were also conducted.

3.3.1 Historic Analytical Parameters

The number and types of contaminants analyzed in RMA waters has changed over time due to changes in environmental concerns, improved analytical methods, changing RMA activities and increased knowledge of contaminant fate and migration. As previously mentioned in Section 1.0, the first investigations of groundwater contamination were conducted in the mid-1950s in response to claims of crop losses by farmers utilizing groundwater from the alluvial aquifer for irrigation purposes. The primary contaminants identified were chloride, fluoride and 2,4-D-like chemicals (Wingfield, 1977, RIC#81266R68).

In 1974, diisopropylmethyl phosphonate and dicyclopentadiene were identified in surface water moving off-post (Wingfield, 1977, RIC#81266R68). In response, a regional hydrologic surveillance program (360° Monitoring Program) was initiated and diisopropylmethyl phosphonate, dicyclopentadiene and a number of other major contaminants were identified in RMA groundwaters. In addition to chloride, diisopropylmethyl phosphonate and dicyclopentadiene, other major contaminants were identified at RMA. These include: aldrin, dieldrin, endrin, isodrin, dithiane, oxathiane, chlorophenylmethyl sulfide, chlorophenylmethyl sulfoxide and chlorophenylmethyl sulfone. Since 1978, DBCP, a nematocide shipped from RMA by rail from 1970 to 1975, has been identified in off-post groundwater.

Chloride originated from various brine solutions utilized in industrial processes and from cooling water discharges. DBCP, dicyclopentadiene, chlorophenylmethyl sulfide, chlorophenylmethyl sulfoxide, chlorophenylmethyl sulfone, aldrin, dieldrin, endrin and isodrin are all related to Shell pesticide manufacturing activities. Diisopropylmethyl phosphonate, fluoride, dithiane and oxathiane are all associated with Army production or demilitarization of munitions.

Most recent investigations have also identified a number of volatile organic compounds distributed widely in the RMA groundwater. These include toluene, xylene, benzene, chlorobenzene, chloroform, methylene chloride, carbon tetrachloride, dichloroethylene, trichloroethylene and tetrachloroethylene (Spaine *et al.*, 1984, RIC#85133R04). These were first detected at elevated levels in 1982.

The most significant contaminants continue to be chloride, diisopropylmethyl phosphonate, dithiane, oxathiane, aldrin, dieldrin, endrin, dicyclopentadiene, DBCP, chlorophenylmethyl sulfide, chlorophenylmethyl sulfoxide and chlorophenylmethyl sulfone. The relative significance of these contaminants is based on their widespread occurrence, potential origin in RMA industrial operations, concentration and environmental fate and impact. Table 3.3-1 is a comparison of analytical suites from selected historic programs with those of recent Remedial Investigation tasks.

Table 3.3-1 Target Analyte Lists for Tasks 25, 36, 38, 39 and 44
(Page 1 of 2)

Analyte	25	36	38	39	44	Basin F ⁸	360*	NBCS*	NWBCS*	WES*
Hexachlorocyclopentadiene	X	X		X	X	X		X	X	X
Aldrin	X	X		X	X	X		X	X	X
Isodrin	X	X		X	X	X		X	X	X
Chlordane	X	X		X	X	X		X	X	X
Dieldrin	X	X		X	X	X		X	X	X
Endrin	X	X		X	X	X		X	X	X
Dichlorodiphenylethane	X	X		X	X	X		X	X	X
Dichlorodiphenyl trichloroethane	X	X		X	X	X		X	X	X
Dicyclopentadiene	X	X		X	X	X		X	X	X
Methylisobutyl ketone	X	X		X	X	X		X	X	X
DBCP	X	X		X	X	X		X	X	X
Dimethylmethyl phosphonate	X	X		X	X	X		X	X	X
Diisopropylmethyl phosphonate	X	X		X	X	X		X	X	X
Dimethyldisulfide	X	X		X	X	X		X	X	X
Benzothiazole	X	X		X	X	X		X	X	X
Oxathiane	X	X		X	X	X		X	X	X
Dithiane	X	X		X	X	X		X	X	X
Chlorophenylmethyl sulfide	X	X		X	X	X		X	X	X
Chlorophenylmethyl sulfoxide	X	X		X	X	X		X	X	X
Chlorophenylmethyl sulfone	X	X		X	X	X		X	X	X
Benzene	X	X		X	X	X		X	X	X
Toluene	X	X		X	X	X		X	X	X
Ethylbenzene	X	X		X	X	X		X	X	X
metaxylene	X	X		X	X	X		X	X	X
ortho- and para- xylenes	X	X		X	X	X		X	X	X
Methylene chloride	X	X		X	X	X		X	X	X
1,1-Dichloroethylene	X	X		X	X	X		X	X	X
1,1-Dichloroethane	X	X		X	X	X		X	X	X

Table 3.3-1 Target Analyte Lists for Tasks 25, 36, 38, 39 and 44
(Page 2 of 2)

Analyte	25	36	38	39	44	Basin F ⁸	360°	NBCS ⁺	NWBCS ⁺	WES ⁺
T-1,2-dichloroethylene	X	X	X	X	X					X ^o
Chloroform	X	X	X	X	X					X
1,2-Dichloroethane	X	X	X	X	X					
1,1,1-Trichloroethane	X	X	X	X	X					X
Carbon Tetrachloride	X	X	X	X	X					X
Trichloroethylene	X	X	X	X	X					X
1,1,2-Trichloroethane	X	X	X	X	X					X
Tetrachloroethylene	X	X	X	X	X					X
Chlorobenzene	X	X	X	X	X					X
Chloride	X	X	X	X	X	X	X	X	X	X
Fluoride	X	X	X	X	X	X	X	X	X	X
Sulfate	X	X	X	X	X	X	X	X	X	X
Nitrate	-	X	X	X	X	X	X	X	X	X
Calcium	-	X	X	-	X	X	X	X	X	X
Magnesium	-	X	X	-	X	X	X	X	X	X
X										X Sodium-X-XX
Potassium	-	X		-	X					
Total Cadmium	-	X		-	X					
Total Chromium	-	X		-	X					
Total Copper	-	X		-	X					
Total Lead	-	X		-	X					
Total Zinc	-	X		-	X					
Total Mercury	-	X		-	X					
Total Arsenic	X	X		X	X					

Last proposed analytical suite.

+ Reported as total xylenes.

o Reported as total dichloroethylenes.

Source: ESE, 1988.

3.3.2 Recent Program Analytical Parameters

As previously stated, the analytical suite for Remedial Investigation tasks is greatly expanded relative to those used in early RMA analysis programs. Table 3.3-1 presents the most recent Task 44 analytical schedule and compares this with those of both recent and historical tasks. This analytical schedule consists of 52 compounds analyzed by quantitative methods and includes 7 organochlorine pesticides, dicyclopentadiene, methylisobutylketone, diisopropylmethyl phosphonate, dimethylmethyl phosphonate, DBCP, 6 organosulfur compounds, 5 volatile aromatics, 12 volatile halogenated organics, 15 inorganic parameters, benzothiazole and chlordane. The current analytical list was derived from various sources that included:

- o An evaluation of contaminant source characteristics at RMA and compounds attributable to activities at these sites;
- o A review of the historical chemical data and recognition of compounds previously detected; and
- o Additional input from the Organizations and the State.

Analytical schedules were modified for each task based on task objectives, although Task 44 analyses included all compounds for each sampling event. Individual task reports discuss rationale regarding analytical suite selection. Analytical results for Task 44 First Quarter FY87, Second Quarter FY87 and Fourth Quarter FY87 are included in Appendix C.

Gas chromatograph/mass spectrometry (GC/MS) nontarget identification and confirmation were conducted under Tasks 4 and 44. A total of 131 wells had samples collected during the Third and Fourth Quarter of Task 4 and Third Quarter of Task 44 (April to June 1987). Thirty-one of these wells had samples analyzed by these techniques to confirm sample results and to identify previously unrecognized compounds that may be added to the target analyte list. GC/MS results are discussed in Section 4.3.

4.0 NATURE AND EXTENT OF CONTAMINATION

Numerous groundwater programs have been conducted during the past 12 years to assess the nature and extent of contamination on a regional and site-specific basis (Section 3.2). This section provides a description of the contaminant distribution in both surface and groundwater at RMA that are based on the hydrogeologic frameworks established in Section 2.0.

In Section 4.1, current surface water contaminant occurrences and magnitudes are presented based on the most recent sampling event. A comparison of historic surface water contaminant distribution is also included.

Groundwater contaminant plume maps are presented in Section 4.2. These were constructed from Third Quarter FY87 data which are from the most recent, comprehensive and contemporaneous sampling event conducted to date. Contaminant concentration and distribution relative to the Unconfined Flow System and individual Denver Formation sand zones are discussed both for individual compounds and for compound groups. Comparisons of historic contaminant distribution with the Third Quarter FY87 plumes are also presented.

The GC/MS analytical results are presented and discussed in Section 4.3. This section is organized into subsections that describe the primary objectives of the GC/MS analysis, the confirmation of target analytes historically and concurrently identified by GC methods and the tentative identification of nontarget analytes. Additionally, concentrations reported by GC and GC/MS methods are compared and discussed. Based on these evaluations, recommendations for modifying the target analyte list are presented.

4.1 Surface Water Quality

An evaluation of surface water quality is an important component when assessing contaminant migration. Surface water may become contaminated from a number of sources including direct placement of contaminants into surface water, flushing of contaminants from surrounding soil or discharge of contaminated groundwater into surface water features.

Surface water quality analytical results frequently display a high degree of variability as a result of changing surface water conditions. For example, within the RMA boundaries, First Creek exhibits chemical concentrations that are substantially higher during storm flows. This may result from scouring of stream channels and flushing of soil contaminants into the stream. Conversely, the off-post reach of First Creek receives groundwater discharge, and any contaminant concentrations within this discharge are diluted by storm-related surface water events. In addition to stream discharge and contaminant source variability, contaminant mixing, sampling technique and the sampling season affect analytical results.

The present surface water quality sampling network is essentially an expansion of the 360⁰ Monitoring Program design. Some of these sites were not sampled regularly due to drainage system modifications or because the surface water was frozen or not flowing. All of the sites within this original network were retained to maintain a network that is sampled regularly and can be referenced for comparison of historical surface water quality with more recent analytical results. The number of on-post sample sites have been increased from the 11 sites of the original 360⁰ sampling program network to the current 52 sites. Not all of these sites are sampled during the same time period. Figure 4.1-1 contains the sample sites corresponding to the present network configuration. Sites that could not be sampled by ESE due to weather conditions are also shown. Table 4.1-1 lists each sample site, its location and additional comments about the location where appropriate.

Surface water quality analytical results are presented on Figures 4.1-2 and 4.1-3. Figure 4.1-2 shows analyte detections corresponding to the Third Quarter FY87 sampling period. This figure is presented to provide a representation of contaminant distribution for a discrete point in time. The Third Quarter FY87 period was selected because sampling included the greatest number of sites and was the most recent, comprehensive sampling event. Data presented in Figure 4.1-2 are included in Table 4.1-2. Arsenic concentrations exceeding 50 ug/l are only shown in Figure 4.1-2.

Figure 4.1-3 shows the locations where multiple detections of analytes occurred in samples collected from Fall 1985 through Fall 1987. Mean contaminant concentration values for this sampling period are also presented on Figure 4.1-3. One-time detections of contaminants were excluded from this figure to place more emphasis upon the multiple

Table 4.1-1 Surface Water Sampling Sites and Sample Representation
(Page 1 of 3)

Site I.D.	Location	Comment
01-001	Uvalda Interceptor at North Gage	Uvalda Interceptor between North and South Gages
01-002	Pond South of South Plants Water Tower	Source Unknown
01-003	South Plants Ditch at Gage	Ditch Discharges
01-004	Lower Derby Lake	Uvalda Interceptor, Upper Derby Lake & South Plants
01-005	Upper Derby Lake	Uvalda Interceptor
02-001	Lake Ladora Weir Gaging Site	Lower Derby Lake Releases
02-002	Sand Creek Lateral above South Plants	Havana Pond or Lower Derby Lake releases
02-003	Lake Mary inlet culvert	Underground storage flushings
02-004	Lake Ladora spillway ditch at C Street	Lake Ladora and Lake Mary overflows
02-005	South Plants southwest drainage ditch	Ditch contaminants and process water
02-006	Sand Creek Lateral below South Plants	Combined flow of 02-005 and 02-002
02-007	Lake Ladora	02-001, groundwater discharges
03-001	Rail Classification Yard north drainage	Rail Classification Yard drainage
03-002	Lake Ladora overflow empoundment	02-004 downstream
05-001	First Creek at 6th Avenue	First Creek entering RMA
06-001	Toxic Gas Yard	Toxic Gas Yard drainage
07-001	Far east branch Uvalda Interceptor	Uvalda Interceptor entering RMA

Table 4.1-1 Surface Water Sampling Sites and Sample Representation
(Page 2 of 3)

Site I.D.	Location	Comment
07-002	Uvalda Interceptor at E Street	Uvalda Interceptor entering RMA
08-001	First Creek at East Boundary	First Creek entering RMA
08-002	Highline Lateral at F Street	Highline Lateral entering RMA
11-001	Peoria Interceptor at gage	Peoria Interceptor entering RMA
11-002	Havana Interceptor at gage	Havana Interceptor entering RMA
11-003	Havana Pond outlet	Havana Pond releases or seepage
11-004	Havana Pond at gage	Havana and Peoria Interceptor discharges
12-001	Center branch of Uvalda Interceptor	Center branch above mixing point
12-002	West branch of Uvalda Interceptor	Uvalda Interceptor entering RMA
12-003	Rod and Gun Club Pond overflow at 6th Avenue	Rod and Gun Club Pond overflow/ groundwater discharges
12-004	South Boundary ditch	Surface drainage entering RMA
12-005	South Uvalda at gage	Combined Uvalda Interceptor flows entering RMA
12-006	Gun Club Pond	Local runoff, Lower Derby Lake overflows
24-001	STP effluent	STP effluent
24-002	First Creek at North Boundary	First Creek exiting RMA
24-003	North Bog inlet ditch	Local surface drainage
24-004	Marsh overflow ditch	Marsh overflows to First Creek

Table 4.1-1 Surface Water Sampling Sites and Sample Representation
(Page 3 of 3)

Site I.D.	Location	Comment
24-005	East Lagoon inlet pipe	Unknown source
24-006	West Lagoon inlet pipe	Unknown source
24-007	First Creek at gage	First Creek above NBCS
26-001	Northwest corner Basin C	Basin B overflow and local runoff
30-001	North Plants drainage at E Street	North Plants drainage upstream of First Creek
30-002	First Creek below 30-001	First Creek and North Plants drainage
31-001	Toxic Storage Yard drainage ditch	Toxic Storage Yard drainage and groundwater
31-002	First Creek at impoundments	First Creek upstream of Toxic Storage Yard
35-001	Caustic Waste Basin	Local runoff
35-002	Basin A overflow ditch	Basin A overflow
35-003	Basin B	35-002 and local runoff
36-001	Basin A at gage	South Plants surface-water/ groundwater discharges
36-002	Basin A overflow	Central pool overflow and local runoff
36-003	Basin A central pool	Groundwater and local runoff

Source: ESE, 1988.

Table 4.1-2 Surface Water Analyte Detections, Spring 1987
(Page 1 of 2)

Site I.D.	Analyte	Concentration (ug/l)
02-005	Endrin	4.44
	Dieldrin	12.3
	Aldrin	3.22
	Arsenic	15.9
02-006	Endrin	0.113
	Dieldrin	1.13
	Aldrin	0.166
	Chloroform	5.78
01-002	DBCP	1.08
	Benzothiazole	18.4
	Chlorophenylmethyl sulfide	52.9
	Chlorophenylmethyl sulfoxide	0.204
	Chlorophenylmethyl sulfone	0.291
	Arsenic	11.5
07-001	Benzothiazole	1.76
11-001	Benzothiazole	12.0
	1,1,1-Trichloroethane	1.92
	Arsenic	4.61
11-003	Benzothiazole	2.06
14-BDD	Diisopropylmethyl phosphonate	74.6
	Arsenic	4.10
24-001	DBCP	0.150
	Aldrin	0.361
	Dieldrin	0.105
	Chloroform	11.4
	Arsenic	28.7
36-001	Endrin	5.16
	Dieldrin	10.8
	DBCP	66.9
	Dicyclopentadiene	31.5
	Methylisobutyl ketone	>104
	Chlorophenylmethyl sulfide	44.3
	Chlorophenylmethyl sulfoxide	61.7
	Chlorophenylmethyl sulfone	797
	Toluene	>8.89
	Benzene	176
	Arsenic	266

Table 4.1-2 Surface Water Analyte Detections, Spring 1987
(Page 2 of 2)

Site I.D.	Analyte	Concentration (ug/l)
36-001	Ethylbenzene ortho- and para-xylenes	>8.09 >18.1
36-003	Endrin Dieldrin Chlorophenylmethyl sulfoxide Chlorophenylmethyl sulfone Arsenic Chloride	9.36 47.9 135 25.5 1,240 252,000
35-003	Diisopropylmethyl phosphonate Endrin Dieldrin Chlorophenylmethyl sulfoxide Chlorophenylmethyl sulfone 1,4-Dithiane Chloride Arsenic	120 1.59 4.10 16.7 162 3.57 621,000 703
05-001	Arsenic	3.79
02-004	Arsenic	10.5
01-001	Arsenic	2.56
11-002	Arsenic	4.20
12-001	Arsenic	2.77
12-004	Arsenic	3.79
13DCC	Arsenic	3.50
24-007	Arsenic	5.01
24-008	Arsenic	2.56
31-002	Arsenic	7.27

Note: A complete listing of surface water quality data for Spring 1987, including analytes that were not detected, is provided in Appendix B.

Source: ESE, 1988.

detections which may be more indicative of verifiable contaminant occurrence. Detections that occurred at sites that were sampled only once between Fall 1985 and Fall 1987 were also plotted since data to confirm or deny the occurrence were unavailable. Table 4.1-3 contains a complete list of all surface water detections of organic analytes, including the off-post area, for this period. Table 4.1-4 contains all of the arsenic occurrences detected from Fall 1985 through Fall 1987.

A comparison of Figures 4.1-2 and 4.1-3 shows there is little difference between analyte concentration at given sites through time, although a smaller variety of analytes were detected during the 1987 sampling period than had been detected historically. The number of compounds detected at eight of the eleven sites varied between the two time periods shown in the figures. This is especially evident for Site 36-001 where only 13 of the 22 multiple-detected compounds (Figure 4.1-3) were detected in the Third Quarter FY87 sampling period.

Few analytes were detected in surface waters entering RMA. Benzothiazole and 1,1,1-trichloroethane were the two most commonly detected analytes. Benzothiazole was detected in the Havana Pond outflow and the South Plants Pond (Figure 4.1-3). During the Third Quarter FY87 sampling event, benzothiazole was detected in Peoria Interceptor and the eastern most branch of the Uvalda Interceptor at the south boundary of RMA. 1,1,1-trichloroethane was detected in Peoria Interceptor and Basin A (Site 36-001) (Figure 4.1-2). Many other polychlorinated ethanes were also detected at Site 36-001. Tetrachloroethane was detected downstream of the Uvalda Interceptor at Ladora Weir in the Third Quarter FY87 sampling.

Diisopropylmethyl phosphonate has not been detected in First Creek as it enters the RMA eastern boundary since 1985. Historically diisopropylmethyl phosphonate was detected in 4 out of 32 samples collected from this area as part of the 360° program between 1976 and 1985. These detections are unusual because diisopropylmethyl phosphonate is a by-product of GB which was produced in the North Plants area, located in excess of three miles to the northwest. Diisopropylmethyl phosphonate is considered directly attributable to RMA activities, and is not thought to occur in upgradient off-post areas.

Table 4.1-3 Complete Organic Analyte Detections in Surface Water from Fall 1985
Through Fall 1987
(Page 1 of 3)

Sampling Site	Detections/ No. of Samples	Analyte	Arithmetic Mean (ug/l)	Range (ug/l)
01-001	0/5		0	0
01-002	2/4	DBCP	0.708	<0.130-1.08
	1/4	Aldrin	0.530	<0.083-0.530
	3/4	Dieldrin	0.571	<0.055-0.913
	1/1	Benzothiazole	18.4	--
	4/4	Chlorophenylmethyl sulfone	198.7	85.8-298
	3/4	Chlorophenylmethyl sulfoxide	89	<4.20-204
	2/4	Chlorophenylmethyl sulfide	27.5	<1.30-52.9
	2/4	Toluene	4.94	<1.21-8.37
	1/4	Benzene	1.98	<1.34-1.98
01-003	1/1	DBCP	0.285	--
01-004	0/1	-	0	0
01-CDD	1/8	Diisopropylmethyl phosphonate	13.0	<10.5-13.0
	1/8	Benzene	14.6	<1.34-14.6
	1/8	Chloroform	1.20	1.20-<1.40
	3/8	Tetrachloroethylene	4.64	<1.30-7.34
	1/8	Trans 1,2-dichloroethylene	1.82	<1.2-1.82
01-DCC	0/7	-	0	0
02-001	0/5	-	0	0
02-003	0/1	-	0	0
02-004	1/4	Chloroform	18.1	<1.40-18.1
02-005	3/3	Aldrin	1.43	0.359-3.22
	3/3	Dieldrin	4.67	0.739-12.3
	1/3	Endrin	4.44	<0.052-4.44
02-006	1/1	Aldrin	0.166	--
	1/1	Dieldrin	1.13	--
	1/1	Endrin	0.113	--
	1/1	Chloroform	5.78	--
02-007	0/1	-	0	0
02-008	0/1	-	0	0
03-002	0/1	-	0	0
05-001	0/4	-	0	0
06-CBB	1/3	Diisopropylmethyl phosphonate	16.9	<10.5-16.9
07-001	1/2	Benzothiazole	1.76	1.76-<2.00
07-002	0/1	-	0	0
07-004	0/1	-	0	0
07-BAA	1/8	Diisopropylmethyl phosphonate	22.0	<10.5-22.0
	1/8	Chloroform	7.96	<1.40-7.96
	1/8	1,2-Dichloroethane	1.17	<0.610-1.17
08-001*	1/10	Aldrin	0.20	<0.070-0.20

Table 4.1-3 Complete Organic Analyte Detections in Surface Water from Fall 1985
Through Fall 1987
(Page 2 of 3)

Sampling Site	Detections/ No. of Samples	Analyte	Arithmetic Mean (ug/l)	Range (ug/l)
08-ADD	1/10	Dieldrin	0.060	<0.060-0.060
	1/10	Diisopropylmethyl phosphonate	11	<10.5-11.0
08-002	0/2	-	0	0
11-001	1/5	Aldrin	0.200	<0.070-0.200
11-001	1/2	Benzothiazole	12.0	<1.70-2.93
	2/5	1,1,1-Trichloroethylene	2.43	--
11-002	0/1	-	0	0
11-003	1/1	Benzothiazole	2.06	--
11-004	0/3	-	0	0
12-001	1/4	Aldrin	0.100	<0.070-0.100
12-002	0/3	-	0	0
12-004	0/3	-	0	0
12-005	0/3	-	0	0
12-AAB	1/8	Aldrin	0.100	<0.070-0.100
24-002	1/6	Aldrin	0.200	<0.070-0.200
13DCC	1/6	Dieldrin	0.080	<0.060-0.080
14BDD	2/7	Dicyclopentadiene	27.9	<9.31-31.5
	1/7	Dieldrin	0.062	<0.060-0.062
	7/7	Diisopropylmethyl phosphonate	215	58.0-550
	2/7	1,4-Dithiane	2.49	<1.1-2.76
	1/6	1,2-Dichloroethane	0.754	<0.610-0.754
22CAA	0/6	-	0	0
24-001	1/5	DBCP	0.15	<0.13-0.15
	5/5	Aldrin	0.853	0.080-2.98
	4/5	Dieldrin	0.332	<0.060-0.936
	2/5	Chloroform	8.1	<1.40-11.4
24-003	0/1	-	0	0
24-007	0/1	-	0	0
24-008	0/2	-	0	0
30-002	0/5	-	0	0
31-001	1/4	Aldrin	0.080	<0.070-0.080
33ABB	0/8	-	0	0
35-003	1/1	Dieldrin	4.10	--
	1/1	Endrin	1.54	--
	1/1	Diisopropylmethyl phosphonate	120	--
	1/1	Chlorophenylmethyl sulfone	162	--
	1/1	Chlorophenylmethyl sulfoxide	16.7	--
36-001	4/5	DBCP	3.8	>2.2-140
	4/5	Dicyclopentadiene	32.8	<9.31-70.2
	5/5	Methylisobutyl ketone	1048	>104-2,800
	2/4	Hexachlorocyclopentadiene	1.85	<1.40-2.45

Table 4.1-3 Complete Organic Analyte Detections in Surface Water from Fall 1985
Through Fall 1987
(Page 3 of 3)

Sampling Site	Detections/ No. of Samples	Analyte	Arithmetic Mean (ug/l)	Range (ug/l)
36-003	2/5	Aldrin	2.03	<0.700-3.07
	4/5	Dieldrin	6.7	3.75->20.8
	3/5	Endrin	2.70	<1.04-5.16
	1/5	Diisopropylmethyl phosphonate	32.0	<10.5-32.0
	1/5	Dimethylmethyl phosphonate	17.3	<15.2-17.3
	5/5	Chlorophenylmethyl sulfone	1389	>110-1870
	5/5	Chlorophenylmethyl sulfoxide	58.3	26.0-87.1
	1/5	1,4-Dithiane	1.46	<1.10-<1.59
	4/5	Toluene	25.0	<12.1-41.2
	5/5	Benzene	53.8	1.72-176
	4/5	Ethylbenzene	54.0	<1.28-102
	5/5	ortho- & para-xylenes	214	18.1-286
	5/5	Chloroform	432	188-641
	5/5	Chlorobenzene	1101	15.8-1700
	1/5	Methylchloride	7.85	<5.00-7.85
	5/5	Tetrachloroethylene	83.0	43.1-130
	4/5	Trans 1,2-Dichloroethylene	4.38	<1.10-5.70
	3/5	1,1,1-Trichloroethane	2.87	<1.70-3.25
	4/5	1,1,2-Trichloroethane	4.01	<1.00-5.93
	4/5	Trans 1,2-Dichloroethylene	8.93	1.20-12.2
	5/5	Trichloroethylene	45.5	19.7-62.0
	1/2	Aldrin	4.98	4.98-<8.30
	2/2	Dieldrin	45.6	43.3-47.9
	1/2	Diisopropylmethyl phosphonate	27.6	<10.5-27.6
	2/2	Chlorophenylmethyl sulfone	172	125-208
	1/2	1,4-Dithiane	3.57	<1.10-3.57
	1/2	Chloroform	2.14	<1.40-2.14
	1/2	Chlorobenzene	3.82	<0.580-382
	1/2	1,1,2-Trichloroethane	7.85	<1.00-6.85
	1/2	1,2-Dichloroethane	6.14	<0.610-6.14

Note: Arithmetic means are based solely on values above CRL.

Source: ESE, 1988.

Table 4.1-4 Arsenic Detections in Surface Water From Fall 1985 Through Fall 1987

Arsenic	Detections	Arithmetic Mean (ug/l)	Range (ug/l)
01 - 001	1/2	2.56	2.56 - <3.07
01 - 002	1/1	11.5	--
01 - CDD	2/7	25.9	<2.5 - 33.4
02 - DCC	1/7	2.98	2.98 - <4.00
02 - 004	1/1	10.5	--
02 - 005	1/2	15.9	<3.07 - 15.9
05 - 001	1/2	3.79	<3.07 - 3.79
07 - ABB	1/6	14.4	<2.50 - 14.4
07 - BAA	2/6	5.31	<2.50 - 6.26
08 - ADD	1/8	6.55	<2.50 - 6.55
11 - 001	1/1	4.61	--
11 - 002	1/2	4.20	<3.07 - 4.20
12 - 001	1/1	2.77	--
12 - 004	1/1	3.79	--
12 - AAB	1/6	4.72	<2.50 - 4.72
24 - 002	1/2	3.50	3.50 - <3.90
14 - BDD	3/6	5.31	2.78 - 9.04
22 - CAA	1/5	2.96	2.96 - <3.07
24 - 001	2/2	33.7	28.7 - 38.7
24 - 007	1/1	5.01	--
24 - 008	1/2	2.56	2.56 - <3.07
31 - 002	1/2	7.27	<3.07 - 7.27
35 - 003	1/1	703*	--
36 - 001	1/1	324*	--
36 - 001	1/1	1240*	--

* Above Certified Reporting Limit

Note: Arithmetic means are based solely on values above CRL.

Source: ESE, 1988.

Numerous surface water contaminant detections occur in surface water samples collected from the South Plants area. DBCP was present in the South Plants Ditch and South Plants Sedimentation Pond (01-002) samples. Chlorophenylmethyl sulfide, chlorophenylmethyl sulfoxide and chlorophenylmethyl sulfone were detected in the South Plants Pond as well as in surface water samples from Basins A and B. Sand Creek Lateral samples collected at the southwest corner of the South Plants area contained aldrin, endrin and dieldrin, and a site further downstream also contained chloroform. Soil samples within Sand Creek Lateral also contain aldrin and dieldrin with concentrations decreasing downstream from the South Plants area.

Water quality of Lower Derby Lake, Ladora Lake and Lake Mary generally is good. In recent years, few contaminants have been detected in the lakes or associated inflow and outflow ditches. Low levels of benzene occasionally have been detected in Ladora Lake. Chloroform has been detected in the overflow basin west of Lake Mary. Organochlorine pesticides, including dieldrin, have been detected in ditches above Ladora Lake, Lake Mary and the Derby lakes. Historically, these compounds were detected on a frequent basis. In recent years, detections have been rare.

The Basin A surface water sample collected near the lime settling ponds contained a majority of the contaminants included on the analyte list. Samples collected from a downstream pool near the center of Basin A (36-003) contained fewer detectable contaminants, but compounds detected were generally at higher concentrations than at the upstream site. This higher concentration at the central pool of Basin A would be expected considering the history of the basin.

An additional surface water source is the Sewerage Treatment Plant (STP) effluent. Analytes detected within this effluent include aldrin, dieldrin and chloroform. DBCP was also detected once during the Third Quarter FY87 sampling event (Figure 4.1-2). This source is most likely responsible for one-time detections of aldrin and dieldrin in First Creek at the north boundary since the STP effluent ditch is a tributary to First Creek. Detections of dicyclopentadiene, diisopropylmethyl phosphonate and 1,4-dithiane occur in First Creek at the Highway 2 gage.

4.2 Groundwater Quality

The descriptive assessment of alluvial and Denver Formation groundwater quality within the Water Remedial Investigation study area is based primarily on the results of quantitative chemical analyses for selected target analytes collected during the Third Quarter FY87. During this quarterly sampling, groundwater samples were collected under various monitoring programs conducted by ESE/HLA (Tasks 25, 36, 39 and 44) and by Ebasco (Task 38). In areas with limited data, data collected prior to spring 1987 were used to confirm and supplement Third Quarter results. These additional data were obtained from USATHAMA historical files and from the results of EPA monitoring programs conducted from 1985 to 1987 as part of the EPA's First Operable Unit off-post study.

Groundwater samples were collected from a total of 296 alluvial and 176 Denver Formation wells under Tasks 25, 36, 38, 39 and 44 during Third Quarter FY87. The locations of alluvial and Denver Formation wells included in the Third Quarter monitoring network are shown on two base maps presented on Plates 3 and 4. The locations of the 65 alluvial wells included in the EPA monitoring programs are also shown in Plate 3. Wells included in the Third Quarter sampling network are listed in Table 4.2-1. EPA monitoring programs included analyses of alluvial groundwater samples for which mainly volatile aromatic organics and volatile halogenated organics were detected. Because these data are not contemporaneous with Third Quarter FY87 data, EPA analytical results were not considered in plume contouring, but were presented as distribution plots to illustrate contaminant occurrences in the Western Tier off-post area.

The target analyte suite for Task 44 presented in Table 3.3-1 represents a comprehensive list of target analytes for the Third Quarter FY87 monitoring network. However, the analytical suites developed for separate monitoring programs conducted during the Third Quarter were based on objectives specific to each task. Therefore, not all samples collected during the Third Quarter were analyzed for every analyte listed. Target analyte lists for Tasks 25, 36, 38 and 39 are also presented in Table 3.3-1.

Table 4.2-1 Third Quarter FY87 Groundwater Sampling Network
(Page 1 of 2)

Section	Well Number
1	01007*, 01008*, 01012*, 01015*, 01017*, 01020, 01021, 01022*, 01024*, 01025, 01027, 01036, 01037, 01041, 01043, 01047, 01048, 01050
2	02008, 02009*, 02010*, 02011, 02012*, 02014, 02018*, 02019*, 02020, 02021*, 02025*, 02030, 02031*, 02034, 02035*, 02036, 02037, 02038*, 02039, 02043
3	03002, 03003*, 03004*, 03005, 03006*, 03008, 03518, 03523
4	04007, 04008*, 04009*, 04010, 04011*, 04014, 04021, 04024, 04027, 04030, 04038, 04041, 04042, 04044, 04045
5	05001*
6	06002, 06003, 06004*, 06005*
7	07001, 07004*
8	08003, 08005*
9	09002, 09003*, 09005, 09006, 09008, 09010, 09011, 09013
11	11002, 11004*
12	12002, 12003*, 12004*
19	19001, 19003*, 19015*, 19017*
22	22005, 22006, 22008, 22011, 22015, 22016, 22017, 22018, 22019, 22021, 22023, 22024, 22027, 22028, 22030, 22031, 22033, 22043, 22044, 22049, 22051, 22053, 22059, 33065
23	23004, 23007, 23008, 23009, 23010, 23011, 23029, 23033, 23043, 23047, 23049, 23050, 23052, 23053*, 23057, 23058, 23085, 23095, 23096, 23102, 23106, 23108, 23118, 23119, 23120, 23123, 23140, 23142, 23150, 23151, 23160, 23161, 23177, 23178, 23179, 23180, 23181, 23182*, 23183, 23184, 23185, 23186, 23187, 23188, 23189, 23190, 23191, 23192*, 23193, 23196, 23197, 23198, 23200, 23201, 23202, 23203, 23204, 23205, 23208, 23209, 23211, 23218, 23229
24	24003, 24008, 24013, 24024, 24027, 24049, 24063*, 24081, 24086*, 24089*, 24092, 24094, 24101, 24106, 24107, 24108, 24109, 24111, 24112, 24113, 24115, 24117, 24120, 24124, 24127, 24130, 24135, 24136, 24137, 24158, 24159, 24161, 24162, 24163, 24164, 24166, 24167, 24168, 24171, 24172, 24174, 24175, 24179, 24180, 24181, 24182, 24183, 24184, 24185, 24186, 24187, 24188, 24191

Table 4.2-1 Third Quarter FY87 Groundwater Sampling Network
(Page 2 of 2)

Section	Well Number
25	25009*, 25011, 25013*, 25014*, 25015, 25016*, 25017*, 25018, 25021*, 25022, 25023*, 25038, 25039*
26	26006, 26011, 26015, 26017, 26019**, 26020, 26041**, 26057*, 26058*, 26061, 26066, 26067*, 26071*, 26072*, 26073, 26075*, 26076, 26083, 26084*, 26085, 26086, 26088, 26127, 26129*, 26133, 26140*, 26142*, 26147*
27	27001, 27002, 27003, 27005, 27016, 27024, 27026, 27028, 27030, 27031, 27040, 27049*, 27051, 27053, 27054*, 27055*, 27057*, 27062, 27063, 27064, 27068, 27071, 27072, 27073, 27074, 27075, 27076, 27077, 27078
28	28022, 28023, 28026*, 28027, 28028*
30	30009, 30011*
31	31005
32	32002*
33	33001, 33002, 33016*, 33026*, 33030, 33032*, 33033, 33034*, 33039, 33063, 33075, 33077
34	34002, 34003*, 34005, 34006*, 34008, 34009**, 34507, 34508, 34515
35	35013**, 35016*, 35017*, 35023, 35036*, 35037, 35038*, 35039*, 35052, 35054*, 35056*, 35058, 35061, 35062*, 35063, 35065, 35066*, 35067*, 35068
36	36001, 36056**, 36065, 36066*, 36069**, 36075, 36076, 36083*, 36084, 36090*, 36110*, 36112, 36113, 36114*, 36117, 36119, 36121*, 36122*, 36139*, 36154
Off-post	37308, 37309, 37312, 37313, 37316*, 37317*, 37318*, 37319*, 37320, 37321*, 37322, 37323*, 37327, 37330, 37331, 37332, 37333, 37334, 37335, 37336, 37337, 37338, 37339, 37340, 37341, 37342, 37343, 37344, 37345, 37346, 37347, 37348, 37349, 37350, 37351, 37352, 37353, 37354, 37355, 37356, 37357, 37358, 37359, 37360, 37361, 37362, 37363, 37364, 37366, 37367, 37368, 37369, 37370, 37371*, 37372*, 37373, 37374, 37376*, 37377, 37378, 37379, 37380*, 37381, 37383, 37387, 37388*, 37389, 37390*, 37391, 37392, Boller, CHI, XII, XXIA

- * Well screened in confined Denver Fm
- ** Well screened in unconfined Denver Fm (Table 4.2-3)
- Wells with no designation are screened primarily in alluvium (UFS)

Source: ESE, 1988.

APPEND-F TBL

Quantitative analyses for groundwater samples collected during the Third Quarter were performed by one of four laboratories in accordance with USATHAMA and EPA approved methodologies. Sample fractions collected under Tasks 25, 36, 39 and 44 were submitted to ESE laboratories in either Gainesville, Florida or Denver, Colorado. Samples collected under Task 38 were submitted for analysis to two laboratories, California Analytical Laboratory and DataChem. A comparison of certified reporting limits for individual analytes between these laboratories is presented in Table 4.2-2. Third Quarter FY87 analytical data obtained under each task as well as analytical results for the EPA programs may be found in Appendix D.

4.2.1 Investigative Approach

Section 4.2.1 discusses the investigative approach used to assess the nature and extent of contamination and includes:

- o Determination of unconfined Denver Formation wells;
- o Assessment of hydrogeologic controls;
- o Data presentation;
- o Contouring criteria;
- o Identification of major contaminant pathways; and
- o Criteria used for source area assessments.

This information is discussed to provide an understanding of plume map construction, to describe the criteria followed to determine plume configuration and to assess contaminant distribution.

4.2.1.1 Unconfined Denver Formation Wells

Denver Formation wells exhibiting direct interaction with the alluvial groundwater were identified. Chemical data from these wells were assessed with alluvial data and incorporated into the alluvial aquifer discussions because water quality is representative of the alluvial aquifer. However, these were also posted on maps illustrating Denver Formation water chemistry data. This was done because although the water within these wells is considered unconfined, the wells are screened in bedrock and, therefore, represent contaminant occurrence within this portion of the Denver Formation.

Table 4.2-2 Comparison of CRL¹ by Laboratory (ug/l)²
(Page 1 of 2)

	Laboratory			
	ESE-Gainesville	ESE-Denver	DataChem	Enseco Cal Lab
<u>Organochlorine Pesticides</u>				
Aldrin	0.070	0.083	N/A	N/A
Endrin	0.052	0.060	N/A	N/A
Dieldrin	0.060	0.054	N/A	N/A
Isodrin	0.060	0.056	N/A	N/A
Hexachlorocyclopentadiene	0.070	0.083	N/A	N/A
Dichlorodiphenylethane	0.053	0.046	N/A	N/A
Dichlorodiphenyltrichloroethane	0.070	0.059	N/A	N/A
Chlordane			N/A	N/A
<u>Volatile Halocarbons</u>				
Chlorobenzene	0.58	1.36	0.76	N/A
Chloroform	1.40	1.88	0.50	N/A
Carbon tetrachloride	2.40	1.69	1.99	N/A
Trans-1,2-Dichloroethylene	1.20	1.75	0.76	N/A
Trichloroethane	1.10	1.31	0.56	N/A
Tetrachloroethylene	1.30	2.76	0.75	N/A
1,1-Dichloroethylene	1.10	1.85	1.70	N/A
1,1-Dichloroethane	1.20	1.93	0.73	N/A
1,2-Dichloroethane	0.61	2.07	0.73	N/A
1,1,1-Trichloroethane	1.70	1.09	0.80	N/A
1,1,2-Trichloroethane	1.00	1.63	0.78	N/A
Methylene chloride	5.00	2.48	7.40	N/A
<u>Organosulfur Compounds</u>				
Chlorophenylmethyl sulfide	1.30	1.08	N/A	7.5
Chlorophenylmethyl sulfoxide	4.70	1.98	N/A	4.2
Chlorophenylmethyl sulfone	4.2	2.24	N/A	11.5
Dithiane	1.1	1.59	N/A	11.2
Oxathiane	2.00	1.35	N/A	10.0
Dimethyldisulfide	1.80	1.16	N/A	8.0
Benzothiazole	2.00	1.14	N/A	N/A
<u>Volatile Aromatics</u>				
Toluene	1.21	2.10	2.80	2.80
Benzene	1.34	1.92	1.70	1.70
meta-Xylene	1.35	1.04	2.00	N/A
ortho- and para-xylenes	2.47	1.34	3.20	3.20
Ethylbenzene	1.28	0.62	1.40	1.4
Dicyclopentadiene	9.31	9.31	N/A	N/A
Methylisobutyl ketone	12.9	12.9	N/A	N/A
Diisopropylmethyl phosphonate	10.5	10.1	N/A	29.3
Dimethylmethyl phosphonate	15.2	16.3	N/A	18.5
DBCP	0.13	0.13	N/A	0.19

Table 4.2-2 Comparison of CRLs¹ by Laboratory (ug/l)²
(Page 2 of 2)

	Laboratory			
	ESE-Gainesville	ESE-Denver	DataChem	Enseco Cal Lab
<u>Inorganics</u>				
Chloride	4,800	1,590	N/A	N/A
Fluoride	1,200	1,000	N/A	N/A
Sulfate	10,000	5,000	N/A	N/A
Nitrate	--	10	N/A	N/A
<u>Metals</u>				
Arsenic	2.5	2.5	N/A	2.5
Calcium	500	--	N/A	N/A
Sodium	764	--	N/A	N/A
Magnesium	500	--	N/A	N/A
Zinc	20.1	--	N/A	N/A
Cadmium	5.16	--	N/A	N/A
Lead	18.6	--	N/A	N/A
Chromium	5.96	--	N/A	N/A
Copper	7.94	--	N/A	N/A
Potassium	1,296	520	N/A	N/A
Mercury	0.240	0.359	N/A	N/A

N/A Not included in Third quarter FY87 analytical suite for samples analyzed by this laboratory

1 Certified Reporting Limits

2 Micrograms per liter

-- Laboratory not certified for this analyte

Source: ESE, 1988.

Criteria used to identify Denver Formation wells that exhibit unconfined characteristics included evaluation of water-level data relative to nearby alluvial data values at the site, water level history at cluster sites, well construction information and geologic characteristics of both the screened interval and the confining layer. Analyte occurrence, concentration, distribution and concentration variation through time also influenced well categorization. All Denver Formation wells included in the Third Quarter FY87 analysis were evaluated using these criteria.

As a result of these assessments, two basic categories of Denver Formation wells were identified that exhibited interaction with alluvial groundwater: Denver Formation wells that are interconnected with the alluvial system because of poor well construction, and Denver wells that are screened within the unconfined groundwater flow system. Table 4.2-3 lists Denver Formation wells in the Third Quarter FY87 network that exhibit interaction with the alluvial system and the criteria that were met to warrant this inclusion. Wells listed in Table 4.2-3 were posted on both alluvial and Denver plots.

4.2.1.2 Hydrogeologic Controls on Plume Configuration

Interpretations presented in Section 2.0 were used in conjunction with chemical data to assess probable plume configuration. Potentiometric-surface maps were used to assess direction of groundwater flow and contaminant migration direction in the unconfined system and within individual Denver Formation zones. Paleochannels and paleotopographic highs that may influence alluvial groundwater flow and contaminant migration were used as a partial basis for contouring contaminant concentration in areas of limited data. The base of Denver Formation sandstone occurrence maps were considered when contouring contaminant distribution in areas where alluvium is unsaturated.

4.2.1.3 Data Presentation

Individual alluvial and Denver zone plume maps or point plots were constructed for a majority of the compounds on the Third Quarter analyte list. Compounds that are included as alluvial and/or Denver plume maps or point plots are shown in Table 4.2-4.

Table 4.2-3 Unconfined Denver Wells and Designation Justification
(Page 1 of 3)

Well Number	Denver Fm Zone	Justification for Unconfined Designation
01007	VC	Alluvium dry; water table in Denver Fm.
01008	VC	Alluvium dry; water table in Denver Fm.
01012	VC	Alluvium dry; water table in Denver Fm.
01047	VC	Water level equivalent to alluvial water level; questionable well construction.
02018	AU	Alluvium dry; water table in Denver Fm.
04008	3	Water level equivalent to alluvial water level; questionable well construction.
19003	1	Sandstone between bedrock surface and screen top.
23053	2SH	Sand pack extends into the alluvium; poor well construction.
23106	2SH	Sand pack extends into the alluvium; poor well construction.
23182	2	Sandstone between bedrock surface and top of sandpack.
23185	1SH	Sand pack extends into the alluvium; poor well construction.
23202*	2	Water level equivalent to alluvium; very poor well construction data; thin confining layer; chemistry similar to that found in alluvium.
23203*	2	Water level equivalent to alluvium; very poor well construction data; thin confining layer; chemistry similar to that found in alluvium.
23204*	2	Water level equivalent to alluvium; very poor well construction data; thin confining layer; chemistry similar to that found in alluvium.
24063	2SH	Sand pack extends into the alluvium; poor well construction.

Table 4.2-3 Unconfined Denver Wells and Designation Justification
(Page 2 of 3)

Well Number	Denver Fm Zone	Justification for Unconfined Designation
24086	1	Sandstone between bedrock surface and top of sandpack.
24108	1	Alluvium dry; water table in Denver Fm.
24124	1	Sandstone between bedrock surface and screen top.
24127	2	Screen top 2.6 ft below bedrock surface, no sandpack information; water level equivalent to alluvium; questionable well construction.
24130	2SH	Screen top 2.2 ft below bedrock surface, no sandpack information; water level equivalent to alluvium, questionable well construction.
24135	2	Sandstone between bedrock surface and screen top.
24184	2	Screen top 1 ft below bedrock surface, no sandpack information; water level equivalent to alluvium; questionable well construction.
26019	1	Sandpack extends into the alluvium, poor well construction.
26041	1SH	Sandpack extends into the alluvium; poor well construction.
26071	1	Sandstone between bedrock surface and screen top; alluvium dry; water table in Denver Fm.
27049	2	In area of dry alluvium; water level equivalent to regional water table.
27057	3	Weathered claystone between bedrock surface and screen top.
34009	3	Water level similar to water table, questionable well construction.
35013	A	Alluvium dry; water table in Denver Fm.

Table 4.2-3 Unconfined Denver Wells and Designation Justification
(Page 3 of 3)

Well Number	Denver Fm Zone	Justification for Unconfined Designation
36056	VC	Sandpack extends into the alluvium; poor well construction.
36069	VCE	Alluvium dry; water table in Denver Fm.
36090	VC	Alluvium dry; water table in Denver Fm.
36139	As	Sandpack extends into the alluvium; poor well construction.
37323	2	Weathered claystone and siltstone between bedrock surface and screen top.
37371	3	Sandstone between bedrock surface and screen top.

* Tenuous designation

Source: ESE, 1988
HLA, 1988

Table 4.2-4 Presentation of Third Quarter FY87 Data
(Page 1 of 2)

Analyte	<u>Unconfined Flow System</u>		<u>Denver</u>	
	Point Plot	Plume Map	Point Plot**	Plume Map*
Hexachlorocyclopentadiene	X			
Aldrin	X		X	
Isodrin	X		X	
Chlordane	X			
Dieldrin		X	X	
Endrin		X	X	X
Dichlorodiphenylethane	X			
Dichlorodiphenyl- trichloroethane	X		X	
Dicyclopentadiene		X	X	
Methylisobutyl ketone	X			
DBCP		X	X	
Dimethylmethyl phosphonate	X		X	
Diisopropylmethyl phosphonate		X	X	
Dimethyl disulfide	X		X	
Benzothiazole		X	X	
Oxathiane		X	X	
Dithiane		X	X	
Summed Oxathiane/Dithiane		X	X	X
Chlorophenylmethyl sulfide		X	X	
Chlorophenylmethyl sulfoxide		X	X	
Chlorophenylmethyl sulfone		X	X	
Summed Chlorophenylmethyl sulfide/ Chlorophenylmethyl sulfoxide/ Chlorophenylmethyl sulfone		X	X	
Benzene		X	X	X
Toluene	X		X	
Summed Aromatics		X	X	
Ethylbenzene		X	X	
meta-Xylene	X		X	
ortho- and para-xylenes	X		X	
Methylene chloride	X		X	
1,1-Dichloroethylene		X	X	
1,1-Dichloroethane		X	X	
1,1-Dichloroethane	X		X	
1,1,2-Trichloroethylene		X	X	
Chloroform		X	X	
1,2-Dichloroethane		X	X	
1,1,1-Trichloroethane		X		
Carbon tetrachloride		X		

Table 4.2-4 Presentation of Third Quarter FY87 Data
(Page 2 of 2)

Analyte	<u>Unconfined Flow System</u>		<u>Denver</u>	
	Point Plot	Plume Map	Point Plot**	Plume Map*
Trichloroethylene		X	X	
1,1,2-Trichloroethane	X		X	
Tetrachloroethylene		X	X	
Summed Halogenated Organics		X	X	
Chlorobenzene		X	X	X
Chloride		X	X	X
Fluoride		X	X	X
Total Arsenic		X	X	

* Plume maps presented only for significant occurrences in Denver zones.

** Point plots presented only for zones where the analyte was detected above CRL.

Source: ESE, 1988.

Alluvial plume maps included both alluvial and unconfined Denver Formation data, and were constructed for compounds within the major organic contaminant compound groups for which there were 10 or more detections. These maps are referred to as Unconfined Flow System plume maps in following discussions. These include compounds within the organochlorine pesticides, organosulfur compounds, volatile aromatic organics, and volatile halogenated organics. Unconfined Flow System plume maps were also constructed for DBCP, dicyclopentadiene, diisopropylmethyl phosphonate, chloride, fluoride and arsenic. Compounds with too few detections to be presented as plume maps are included in Appendix D as point plots (Table 4.2-4). Inorganic parameters that were not presented as either point plots or plume maps are included in Third Quarter FY87 analytical results (Appendix D).

Concentrations of some compounds were summed to produce composite plume maps (Table 4.2-4). Compounds that are presented as summed compound plume maps are oxathiane/dithiane, chlorophenylmethyl sulfide/chlorophenylmethyl sulfoxide/chlorophenylmethyl sulfone, volatile aromatic organics and volatile halogenated organics. The sulfur compounds are presented as a composite group because individual compounds within the group show similar source, occurrence and concentration. The volatile compounds are presented as composite or summed plume maps to provide a general understanding of the overall compound group distribution.

Of the 52 target analytes, 17 individual compound and composite groups are discussed in the body of the text. These include endrin, dieldrin, DBCP, dicyclopentadiene, diisopropylmethyl phosphonate, benzene, chlorobenzene, chloroform, tetrachloroethylene, trichloroethylene, arsenic, fluoride and chloride. Composite groups discussed are chlorophenylmethyl sulfide/ chlorophenylmethyl sulfoxide/chlorophenylmethyl sulfone, oxathiane/dithiane, total volatile aromatic organics and total volatile halogenated organics. Endrin and dieldrin are presented individually rather than under a composite organochlorine pesticide discussion because organochlorine distribution is dominated predominantly by dieldrin and in a minor aspect by endrin. Endrin and dieldrin also show very different distribution patterns. Aldrin and isodrin occurrence in groundwater is very low and these compounds were therefore not contoured as plumes. DBCP, dicyclopentadiene and diisopropylmethyl phosphonate are discussed individually because they exhibit relatively unique distributions, and have been individual compounds of interest in terms of historical assessments and boundary system studies. Benzene and

chlorobenzene are presented as individual compounds under the volatile aromatic organics discussion because they more heavily influence volatile aromatic organics distribution and individually exhibit different distribution patterns. Trichloroethylene and tetrachloroethylene are also presented individually as well as part of the composite map under the volatile halogenated organic discussion, because they exhibit on-post occurrence and extensive off-post distribution west of RMA that may be non-RMA source related. Chloroform is presented individually as it is the halogenated organic that exhibits the most extensive occurrence and most influences on-post halogenated organic distribution.

Chloride, fluoride and arsenic are also presented individually due to their historic significance and widespread distribution in groundwater. Other inorganic parameters were not presented as plume maps because emphasis had been placed on identifying natural and anthropogenic compounds that have toxic effects of the highest concern.

Only chlorobenzene, benzene, oxathiane/dithiane, dieldrin, chloride and fluoride exhibited enough correlatable detections to contour plumes in confined portions of the Denver Formation. These plumes are presented under compound discussions and all other detections in the Denver Formation are presented as point plots in Appendix D. As previously stated, unconfined Denver Formation well data were plotted, contoured, and interpreted with alluvial data because they are hydrologically interconnected with the Unconfined Flow System. These data are posted on Denver plots to provide a more comprehensive understanding of contaminant occurrence in Denver Formation groundwater although data are contoured with Unconfined Flow System data. Table 4.2-5 summarizes alluvial and unconfined Denver Formation (which comprise the Unconfined Flow System), and confined Denver Formation detections for all compounds included in the body of this report, which are discussed individually or are included in major compound groups. Concentration ranges, median value and the number of detections above the upper certified reporting limits are included in this table.

4.2.1.4 Contouring Criteria

As previously stated, only those organic compounds with 10 or more detections in the alluvium were contoured as plume maps. Contour intervals were based initially on those

Table 4.2-5 Analyte Summary for the Alluvium, Unconfined Denver Fm and Confined Denver Fm, Third Quarter FY87
(Page 1 of 5)

Geologic Unit	No. of Detections vs No. Wells Sampled	Range of Detections (ug/l) ¹	Median (ug/l) ¹	No. of Detections Above the the Upper CRLs ²	Range of Values Greater than the Upper CRLs ²
DIELDRIN					
Alluvium	102/262	0.062-3.48	0.245	9	0.208-1.38
Denver, Unconfined	13/35	0.103-8.92	0.221	2	0.275-0.600
Denver, Confined	10/140	70.05-1.23	0.123	6	0.079-0.275
ENDRIN					
Alluvium	35/262	0.064-1.51	0.321	13	0.120-1.50
Denver, Unconfined	8/35	0.115-1.22	0.234	3	0.300-1.56
Denver, Confined	4/140	>0.057-0.162	0.060	7	0.085-0.300
OXATHIANE					
Alluvium	37/230	1.66-68.6	6.610	0	--
Denver, Unconfined	10/35	1.79-1,950	8.100	0	--
Denver, Confined	5/140	3.09-49.5	12.300	0	--
DITHIANE					
Alluvium	47/232	1.25-498	19.300	1	1.76
Denver, Unconfined	9/35	3.16-7,760	34.800	1	79.5
Denver, Confined	6/140	1.68-263	56.500	0	--
DITHIANE/OXATHIANE COMPOSITE					
Alluvium	47/232	1.25-567	22.495	1	1.76
Denver, Unconfined	11/35	1.79-9,310	27.440	0	--
Denver, Confined	6/140	1.68-312	64.445	0	--
BENZOTHAZOLE					
Alluvium	13/231	1.24-12.8	1.770	0	--
Denver, Unconfined	4/35	5.01-14.6	6.705	1	40.0
Denver, Confined	4/140	1.50-3.56	1.980	0	--
ORGANOSULFUR COMPOSITE					
Alluvium	74/231	2.16-2,054	16.610	0	--
Denver, Unconfined	14/35	3.79-614	22.160	0	--
Denver, Confined	6/140	1.25-11.93	3.645	0	--
CHLOROPHENYLMETHYL SULFIDE					
Alluvium	30/231	0.68-748	5.345	1	2.81
Denver, Unconfined	10/35	3.38-94.3	7.845	1	56.3
Denver, Confined	5/140	1.25-4.09	2.50	0	--

Table 4.2-5 Analyte Summary for the Alluvium, Unconfined Denver Fm and Confined Denver Fm, Third Quarter FY87
(Page 2 of 5)

Geologic Unit	No. of Detections vs No. Wells Sampled	Range of Detections (ug/l) ¹	Median (ug/l) ¹	No. of Detections Above the the Upper CRLs ²	Range of Values Greater than the Upper CRLs ²
CHLOROPHENYLMETHYL SULFOXIDE					
Alluvium	44/230	2.16-148	11.750	1	5.35
Denver, Unconfined	7/35	8.97-392	47.300	1	84.0
Denver, Confined	0/140	--	--	0	--
CLOROPHENYLMETHYL SULFONE					
Alluvium	61/231	2.83-1,390	11.000	2	22.0-112
Denver, Unconfined	9/35	3.28-520	16.500	0	--
Denver, Confined	3/140	3.16-9.58	3.650	0	--
BENZENE					
Alluvium	31/296	1.49-25,000	3.250	4	13.4-134
Denver, Unconfined	5/35	2.15-16,000	7.470	1	26.8
Denver, Confined	27/141	1.63-73.8	4.500	0	--
CHLOROBENZENE					
Alluvium	49/297	0.582-31,200	6.910	2	11.6-58
Denver, Unconfined	3/35	1.74-1,170	55.900	1	11.6
Denver, Confined	24/141	0.79-74.7	16.050	0	--
TOLUENE					
Alluvium	3/296	4.57-8.89	8.110	4	24.2-605
Denver, Unconfined	3/35	1.46-320	>8.890	0	--
Denver, Confined	2/141	2.17-5.20	3.685	0	--
ETHYLBENZENE					
Alluvium	4/296	1.42-7.78	1.895	3	25.6-640
Denver, Unconfined	3/35	1.34-8.09	2.840	1	25.6
Denver, Confined	2/141	1.32-13.7	7.510	0	--
META-XYLENE					
Alluvium	3/263	1.14-8.93	1.520	3	27-675
Denver, Unconfined	1/35	8.93	>8.930	1	27
Denver, Confined	2/141	1.37-45.1	23.235	0	--
ORTHO- & PARA-XYLENES					
Alluvium	3/235	1.49-3.23	1.940	4	49.4-1,240
Denver, Unconfined	1/35	18.1	18.100	1	49.4
Denver, Confined	2/141	3.60-53.4	28.500	0	--

Table 4.2-5 Analyte Summary for the Alluvium, Unconfined Denver Fm and Confined Denver Fm, Third Quarter FY87
(Page 3 of 5)

Geologic Unit	No. of Detections vs No. Wells Sampled	Range of Detections (ug/l) ¹	Median (ug/l) ¹	No. of Detections Above the the Upper CRLs ²	Range of Values Greater than the Upper CRLs ²
CHLOROFORM					
Alluvium	109/297	0.54-38,800.0	16.500	0	--
Denver, Unconfined	19/35	1.99-16,500	24.500	1	28.0
Denver, Confined	19/141	1.71-194	8.790	1	14.0
METHYLENE CHLORIDE					
Alluvium	6/295	6.63-5,780	13.735	4	500-2,500
Denver, Unconfined	3/32	11.7-7,340	58.900	1	4,400
Denver, Confined	1/138	6.76	6.760	0	--
CARBON TETRACHLORIDE					
Alluvium	9/297	2.96-16.8	6.090	8	12-1,200
Denver, Unconfined	2/35	52-177	114.500	3	24-120
Denver, Confined	2/141	5.55-7.6	6.575	2	4.8-24
1,1,1-TRICHLOROETHANE					
Alluvium	24/297	0.80-102	8.935	9	8.5-850
Denver, Unconfined	0/35	--	--	3	17-85
Denver, Confined	0/141	--	--	2	3.4-17
1,1,2-TRICHLOROETHANE					
Alluvium	7/297	0.80-36.8	1.610	6	2-500
Denver, Unconfined	1/35	4.47	4.470	2	5-20
Denver, Confined	0/141	--	--	1	5
1,1-DICHLOROETHANE					
Alluvium	9/297	1.20-9.74	3.270	3	24-600
Denver, Unconfined	3/35	1.57-3.77	2.110	1	24
Denver, Confined	2/141	5.21-8.82	7.015	1	12
1,2-DICHLOROETHYLENE					
Alluvium	26/297	0.636-143.0	5.635	6	11.5-305
Denver, Unconfined	8/35	2.62-474	34.100	1	61
Denver, Confined	2/141	0.97-2.61	1.759	2	2.99-6.1
1,1-DICHLOROETHYLENE					
Alluvium	14/297	2.28-35.6	8.210	4	11/550
Denver, Unconfined	2/35	1.70-4.41	3.055	22	
Denver, Confined	0/141	--	--	0	--

Table 4.2-5 Analyte Summary for the Alluvium, Unconfined Denver Fm and Confined Denver Fm, Third Quarter FY87
(Page 4 of 5)

Geologic Unit	No. of Detections vs No. Wells Sampled	Range of Detections (ug/l) ¹	Median (ug/l) ¹	No. of Detections Above the the Upper CRLs ²	Range of Values Greater than the Upper CRLs ²
TRANS-1,2-DICHLOROETHYLENE					
Alluvium	12/264	1.26-56.7	2.705	4	12-600
Denver, Unconfined	3/35	4.26-14.9	14.000	1	24
Denver, Confined	1/141	5.08	5.080	1	12
TRICHLOROETHYLENE					
Alluvium	90/297	0.71-2,840	5.285	4	2.2-110
Denver, Unconfined	11/35	1.2-175	4.380	2	5.5-22
Denver, Confined	11/141	1.24-8.68	2.550	0	--
TETRACHLOROETHYLENE					
Alluvium	57/297	0.82-926	8.760	3	123-650
Denver, Unconfined	13/35	2.31-184	15.500	1	26
Denver, Confined	3/141	1.54-6.67	3.060	0	--
DBCP					
Alluvium	55/264	0.146-278.0	0.586	0	--
Denver, Unconfined	8/35	0.609-5.57	1.335	0	--
Denver, Confined	5/141	0.191-0.779	0.370	0	--
DICYCLOPENTADIENE					
Alluvium	25/262	10.7-1,200	152.000	5	16.2-21.6
Denver, Unconfined	6/35	16.6-256	128.700	0	--
Denver, Confined	0/139	--	--	5	16.2-21.6
DIISOPROPYLMETHYL PHOSPHONATE					
Alluvium	102/259	11.9-12,100	203.500	0	--
Denver, Unconfined	19/35	11.9-5,230	322.000	0	--
Denver, Confined	11/136	17.0-5,350	127.000	0	--
ARSENIC					
Alluvium	66/257	2.56-315	5.270	0	--
Denver, Unconfined	8/34	4.59-410	17.685	0	--
Denver, Confined	16/138	2.57-26.7	6.460	1	25.2
FLUORIDE					
Alluvium	179/259	1,000-13,400	2290.	2	12,200-30,500
Denver, Unconfined	32/35	1,200-223,000	2410.	1	10,000
Denver, Confined	80/139	913-7,870	1675.	0	--

Table 4.2-5 Analyte Summary for the Alluvium, Unconfined Denver Fm and Confined Denver Fm, Third Quarter FY87
(Page 5 of 5)

Geologic Unit	No. of Detections vs No. Wells Sampled	Range of Detections (ug/l) ¹	Median (ug/l) ¹	No. of Detections Above the the Upper CRLs ²	Range of Values Greater than the Upper CRLs ²
CHLORIDE					
Alluvium	260/259	25,700-6,230,000	187000	0	--
Denver, Unconfined	35/35	5,730-28,200,000	246000	0	--
Denver, Confined	132/139	5,520-7,290,000	57450	0	--

¹ Micrograms per liter

² Certified Reporting Limits

Source: ESE, 1988.

used for Tasks 4 and 25 distribution plots in order to maintain consistency and to allow for comparison of results. Contour intervals were further modified as needed based on individual compound variation and for presentation purposes.

If one laboratory was used to analyze a particular analyte the certified reporting limit for that laboratory is equal to the lowest contour line value. However, several laboratories generally analyzed samples during each sampling quarter and the certified reporting limits for each laboratory for a given compound were slightly different. In this case, the lowest contour interval is equal to the highest certified reporting limit from any of the laboratories. Detected concentration values that are below the highest certified reporting limit are plotted outside of plume boundaries as isolated occurrences. In addition, some analytes were detected at locations that are very distant from known plumes and were plotted as isolated points with the appropriate concentration value.

Some alluvial well cluster sites were included in the sampling network. The highest concentration of a contaminant was contoured at the site with reference to depth concentration variation noted in text discussions.

In some instances, detection levels are reported higher than the actual certified reporting limits. These levels above the upper certified reporting limits are the result of dilution of the sample due to the presence of relatively high concentrations of one or more analytes, within the analytical group. Dilution of the sample results in a subsequent inability to provide a minimum detectable value for the remaining target analytes within the group. A "greater than" value is only reported where the overall contaminant concentration in the sample is fairly high and adequate dilution of the sample to determine an accurate concentration value is not possible. Elevated certified reporting limits were generally not used as control point values when contouring plumes. If an elevated certified reporting limit occurred in an area where a detection would markedly influence plume configuration, the chemical history of that well was evaluated. Where warranted the elevated certified reporting limit was used to influence plume configuration based on occurrence and values of historical concentrations.

Historical data (pre-1987) were used to help define plume geometries where Third Quarter FY87 information was lacking or questionable. Data collected under Task 4 (1985 to 1986) were given preference over older data in this evaluation since the more recent historical

information was collected and analyzed by the same techniques as Third Quarter data, making comparisons more valid. Historical values were not posted on the plume maps. If historical data were used to augment Third Quarter information, the use of these data were documented in individual compound discussions.

The Transitional Monitoring Program (TMP) was conducted following the Third Quarter FY87 program during the summer and fall of 1987 by R.L. Stollar & Associates, Inc. Although it was not part of the Water Remedial Investigation, comparisons of preliminary TMP plume maps and those presented in the following Water Remedial Investigation discussions indicate that contaminant distributions do not vary substantially in terms of either distribution and contaminant concentration. The reader is referred to the forthcoming CMP Final Report for more detailed comparisons.

4.2.1.5 Identification of Major Contaminant Pathways

Several major contaminant pathways were identified by plume configuration and contaminant occurrence. These pathways were named to standardize contaminant distribution discussions (Figure 4.2-1). Names of pathways were determined based on proximity to well-known features, and are not meant to imply a source-plume relationship.

4.2.2 Dieldrin

Analyses for the compound dieldrin were performed on 438 groundwater samples collected from alluvial and Denver Formation wells during the third quarter of FY87. Dieldrin concentrations ranging from 0.062 to 8.92 ug/l were detected in 125 of the 437 samples analyzed. The distribution of dieldrin in the Unconfined Flow System is illustrated on the plume map presented in Figure 4.2-2. Dieldrin was detected in confined Denver Formation groundwater only within the zones A, 1, 2, and 3. These detections are shown on the concentration point plots presented in Appendix D. The Unconfined Flow System plume map and Denver Formation point plots are discussed in Sections 4.2.2.2 and 4.2.2.3 below. Dieldrin detections in alluvial, unconfined Denver Formation and confined Denver are summarized in Table 4.2-5.

4.2.2.1 Historical Water-Quality Data

Dieldrin is a chlorinated hydrocarbon pesticide that was present in RMA effluent discharges into on-post disposal basins between 1952 and 1973 (Ebasco, 1988, RIC#88357R01).

Historically, dieldrin was detected in both alluvial and Denver Formation groundwater at RMA. Based on Initial Screening Program (Initial Screening Program) data, concentrations in excess of 1.00 ug/l were observed in alluvial groundwater in Sections 1 and 2 of the South Plants area and in the northwest corner of Section 35. Dieldrin was also detected in a limited area in north central Section 27, in the northern portion of Basin C, downgradient through Basin F into the southern part of Section 23, and in the area near the North Boundary Containment System in the northwest corner of Section 24.

Dieldrin was detected in the Unconfined Flow System between 1975 and 1985 in the South Plants area, near Basins A through F, the Northwest Boundary Containment System and the North Boundary Containment System (MKE unpublished data, 1986).

During the Initial Screening Program, a dieldrin plume was identified in Denver Formation groundwater in the vicinity of Basins B, C, D, E and F along the Basin F pathway. Concentrations in excess of 1.00 ug/l were limited to the area just east of Basin C and Basin F. Isolated detections of dieldrin in Denver Formation groundwater were observed during the Initial Screening Program in Sections 2, 4, 19, 25 and 36.

4.2.2.2 Unconfined Flow System

During the Third Quarter FY87, 297 groundwater samples were collected from alluvial and unconfined Denver Formation wells and were analyzed for dieldrin. Of these, 262 samples were collected from wells screened within alluvium and 35 samples were collected from wells screened within the unconfined groundwater flow system in the uppermost Denver Formation. Dieldrin concentrations ranging from 0.062 to 8.92 ug/l were observed in 115 of the 297 groundwater samples analyzed. A summary of analytical results for dieldrin in Denver Formation wells completed within the Unconfined Flow System is presented in Table 4.2-6.

Table 4.2-6 Summary of Analytical Results for Dieldrin for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm

Geologic Unit	No. of Samples Analyzed	No. of Detections	Range of Detection (ug/l) ¹	No. of Detections Above the Upper CRLs ²	Range of Detections Exceeding Upper CRLs ² (ug/l) ¹
ALLUVIUM	262	102	0.062 - 3.48	9	<0.208 - <1.38
DENVER					
B, Unconfined	0	0	--	0	--
B, Confined	3	0	--	0	--
VC/VCE, Unconfined	7	4	0.104 - 2.34	0	--
VC/VCE, Confined	0	0	--	0	--
A, Unconfined	3	0	--	0	--
A, Confined	28	3	>0.050 - 0.149	1	<0.11
1u, Unconfined	0	0	--	0	--
1u, Confined	13	0	--	1	<0.079
1, Unconfined	8	1	8.92	1	<0.600
1, Confined	16	4	0.065 - 0.411	0	--
2, Unconfined	13	7	0.136 - >2.06	0	--
2, Confined	28	1	0.09	1	<0.275
3, Unconfined	4	1	0.103	0	--
3, Confined	20	2	0.125 - 1.230	1	<0.165
4, Unconfined	0	0	--	0	--
4, Confined	19	0	--	0	<0.11
5, Confined	9	0	--	0	--
6, Confined	2	0	--	1	<0.079
7, Confined	2	0	--	0	--

¹ Micrograms per liter

² Certified Reporting Limits

Source: HLA, 1988.

The certified reporting limits used during the analyses of Third Quarter FY87 groundwater samples for dieldrin were 0.054 and 0.06 ug/l.

The distribution of dieldrin in the Unconfined Flow System is shown on the plume map presented in Figure 4.2-2. Within this distribution, six major plumes were identified in the following pathways:

- o Central pathway, south (Section 35 to northwestern Section 34);
- o Central pathway, north (Section 35 to the RMA northwest boundary);
- o South Plants/Basin A, Basin A Neck pathways to northern Section 27;
- o Basin F pathway; and
- o Basin F northwest pathway.

Dieldrin concentrations greater than 0.06 ug/l were also noted in off-post areas downgradient of the RMA north and northwest boundaries. These off-post detections appear to be related to on-post contamination and will be discussed in this section.

The plume identified in the Central pathway, south area trends northwest along a shallow bedrock paleochannel from west-central Section 35 and extends approximately 6,000 ft to northwestern Section 34. Dieldrin concentrations within the plume range from 0.09 to 1.22 ug/l. This plume may be related to dieldrin contamination in the Basin A - South Plants area, or dieldrin contamination within the Sand Creek Lateral.

The plume identified in the Central pathway north area, trends northwest along a bedrock paleochannel from northwestern Section 35 and extends approximately 9,000 ft to the RMA northwest boundary. Dieldrin concentrations within this plume range from 0.12 to 1.76 ug/l. The plume is interpreted to extend upgradient of Well 35037 based on historical detections of dieldrin. The sources that may have contributed to this plume at specific locations are not directly evident, but may include Sand Creek Lateral, Basin F, the general South Plants area and Basin A.

The plume identified along the South Plants/Basin A pathway extends along the Basin A Neck pathway to northern Section 27. The plume extends approximately 12,000 ft in length and ranges in width from less than 500 ft in the Basin A neck to approximately

2,000 ft in Basin A. The extension of this plume as shown in Figure 4.2-2 along the Basin A neck pathway in Sections 26 and 35 was based on historical water-quality data.

Dieldrin concentrations within the South Plants/Basin A plume range from 0.10 ug/l in Well 27026 to 2.34 ug/l in Well 36056, located in southern Basin A. In addition to the South Plants/Basin A pathway area, concentrations in excess of 1.00 ug/l were also noted immediately downgradient of Basin D in southwestern Section 26 and in Well 27064, located in northern Section 27. Probable contaminant sources within the plume include the general South Plants area, Basin A, insecticide pits in Section 36, Basins B through E and chemical sewers in southern Section 26.

The plume trending west in the South Plants pathway (Figure 4.2-1) extends approximately 3,500 ft in length and ranges from about 1,000 to 1,800 ft in width. As indicated in Figure 4.2-2, the occurrence of the plume in eastern Section 2 was based largely on historical water quality data. Dieldrin concentrations within the plume range from 0.08 to 2.94 ug/l. Possible sources of dieldrin in this area included the general South Plants area and pesticide storage areas (MKE, unpublished data, 1986).

Historical data were used to assess the distribution of dieldrin in northeastern Section 27 and southeastern Section 22 along the minor Basin F west pathways (Figure 4.2-1). These data generally indicate that dieldrin is present in these areas at concentrations between 0.06 and 0.50 ug/l. Third Quarter FY87 data indicate that dieldrin concentrations in these areas range from 0.093 to 0.654 ug/l. Although dieldrin was not detected in Well 27016 during the Third Quarter FY87, this well was included within the map area based on previous analytical results from Task 4 and Task 25 sampling events. Basin F is the most probable source for dieldrin contamination in northeastern Section 27 and southeastern Section 22.

An additional plume identified in Figure 4.2-2 occurs in the Basin F pathway and trends north-northeast from Basin F to the North Boundary Containment System. The plume extends approximately 7,500 ft in length and ranges in width from approximately 2,500 ft immediately north of Basin F to nearly 6,000 ft immediately upgradient of the North Boundary Containment System. Dieldrin concentrations within the plume range from 0.090 to greater than 2.06 ug/l with concentrations in excess of 1.00 ug/l extending along the central portion of the plume from Basin F to the North Boundary Containment System.

The highest dieldrin concentrations were noted in Wells 23053 (>2.06 ug/l) and 23106 (2.06 ug/l).

Elevated certified reporting limits were observed north of Basin F at Wells 26041, 23049, 23095, and 23179. These wells were included within the plume based on previous Task 44 and Task 25 analytical results and on the proximity of these wells to Basin F. Dieldrin was not detected in groundwater samples collected from Wells 23120, 23178 and 24181 during the Third Quarter FY87, however, these wells were also included within the plume area based on consistent dieldrin detections during previous Task 44 and Task 25 sampling events.

In addition to the on-post dieldrin plumes discussed above, isolated detections of dieldrin were observed in Sections 1, 2, 19, 23 and 25 (Figure 4.2-2). Isolated detections should be resampled to confirm or refute analytical results of the Third Quarter FY87.

Within downgradient off-post areas, dieldrin contamination was observed both north and northwest of the RMA boundary. This contamination is possibly associated with on-post contamination identified in the vicinity of the North Boundary Containment System and Northwest Boundary Containment System. Description of the dieldrin distributions noted within these two off-post areas is presented below. Contaminant trends in and around the North Boundary Containment System and Northwest Boundary Containment System will be discussed further in Task 36 (ESE, 1988e, RIC#88344R02), Task 25 (ESE, 1988f, RIC#89024R02) and Task 39 (ESE, 1989b, RIC#89024R01).

Two northwest trending plumes were identified in the northwest off-post area as shown in Figure 4.2-2. The southern plume extends approximately 2,000 ft from the RMA boundary to southeastern Section 21. The northern plume extends approximately 5,000 ft from the Northwest Boundary Containment System to southeastern Section 16. The extent of the northern plume was largely inferred from available historical data as indicated in Figure 4.2-2. In general, dieldrin concentrations noted within these plumes were lower than concentrations observed in upgradient on-post areas. These plumes probably have similar sources as the on-post contamination near the Northwest Boundary Containment System. These plumes may represent the remnant downgradient extensions of on-post plumes that extended to the RMA northwest boundary but are separated from on-post contamination due to Northwest Boundary Containment System operations. The southern

plume in this area appears to extend around the southern edge of the Northwest Boundary Containment System.

Three plumes were identified downgradient of the North Boundary Containment System. One plume extends approximately 2,000 ft along the First Creek Off-Post pathway and is approximately 1,000 ft in width on average. Dieldrin concentrations within the plume range from 0.333 to 1.62 ug/l. A second plume was identified downgradient of the North Boundary Containment System in the southern portion of the Northern Off-Post pathway. This plume trends north along this pathway approximately 2,500 ft and is approximately 800 ft wide. Concentrations within the plume range from 0.062 to 0.117 ug/l. The third plume identified downgradient of the North Boundary Containment System is located along the western extension of the North Boundary Containment System in Section 23 on-post. This plume is defined by two wells with dieldrin concentrations of 0.073 and 0.075 ug/l.

The distribution of dieldrin is laterally more extensive upgradient of the North Boundary Containment System than in the northern off-post area. The dieldrin plume appears to spread laterally to the east and west in the area immediately upgradient of the North Boundary Containment System but as discussed above, occurs only within three narrow bands downgradient of the system (Figure 4.2-2). This distribution implies that, in general, the plume is largely contained by the North Boundary Containment System. Dieldrin concentrations detected downgradient of the system may be a result of very minor dieldrin transport beneath the barrier through the unconfined Denver Formation, but are probably more representative of residual contamination.

Several isolated detections of dieldrin were also noted off-post (Figure 4.2-2). Downgradient of the Northwest Boundary Containment System, isolated dieldrin detections were noted approximately 6,000 ft and 9,000 ft from the RMA boundary at Wells 37337 (0.07 ug/l) and 37355 (0.12 ug/l), respectively. Downgradient of the North Boundary Containment System an isolated dieldrin detection was observed at Well 37353 (0.16 ug/l) located approximately 11,000 ft northwest of the RMA boundary. The presence of contamination in these wells should be confirmed or refuted by repeated sampling.

4.2.2.3 Denver Aquifer

During the Third Quarter FY87, 175 groundwater samples from Denver Formation wells were analyzed for dieldrin. Thirty-five of these Denver Formation wells were completed within the unconfined groundwater flow system. The analytical results from these 35 wells are summarized on Table 4.2-6. These results were contoured and discussed in conjunction with the saturated alluvium (Unconfined Flow System) in the preceding section. The results of dieldrin analyses performed on samples collected from the remaining 140 confined Denver Formation wells are summarized on Table 4.2-6.

Based on Third Quarter FY87 analytical results, dieldrin was detected above certified reporting limits in samples collected from confined Denver Formation wells completed within the A, 1, 2 and 3 zones (Table 4.2-6). The locations of wells completed within each of these zones and detected dieldrin concentrations are shown on the point plots presented in Appendix D.

Dieldrin was not detected in groundwater samples obtained from wells screened in the confined portions of the remaining Denver Formation zones. The locations of wells within these zones are shown on the well location maps presented in Appendix D. Well 27054 is the only well shown on these maps that was not sampled for dieldrin. This well is screened within zone 4.

Dieldrin was detected within the confined Denver Formation zone A in Wells 02038, 36110 and 36117. Dieldrin concentrations reported in these wells were >0.050 , 0.15 and 0.12 ug/l, respectively. These wells are located either within or near the zone A subcrop (Plate 7). The dieldrin noted in these wells is possibly related to the occurrence of dieldrin identified within the Unconfined Flow System in the South Plants/Basin A area.

Dieldrin was detected within the confined Denver Formation zone 1 in Wells 26057, 26086, 26140, and 35017. The concentrations of dieldrin noted in these wells were 0.10, 0.12, 0.41 and 0.07 ug/l, respectively. These wells are located upgradient of the zone 1 subcrop in southeastern Section 26 and northeastern Section 35. Dieldrin concentrations are mapped as a plume, and are presented in Figure 4.2-3. The sources for dieldrin observed within zone 1 in these areas are not known. However, these detections may relate to dieldrin contamination within the Unconfined Flow System in the Basin A Neck area.

Dieldrin was detected within Denver Formation zone 2 in Well 24171 at a concentration of 0.09 ug/l. Well 24171 is located immediately downgradient of the North Boundary Containment System and is within the zone 2 subcrop area. This detection may be related to dieldrin contamination within the overlying Unconfined Flow System.

Two dieldrin detections were noted within Denver Formation zone 3 in Wells 24120 and 26142. Dieldrin concentrations reported in these wells were 0.13 and 1.23 ug/l, respectively. Sources for dieldrin contamination in these wells are unknown but may be related to overlying contamination in the Unconfined Flow System. In each case, nearby wells completed in zone 2 do not indicate elevated concentrations of dieldrin.

4.2.3 Endrin

Analyses for the compound endrin were performed on 437 groundwater samples collected from alluvial and Denver Formation wells during the Third Quarter FY87. Endrin concentrations ranging from 0.057 to 1.51 ug/l were detected in 47 of the 437 samples analyzed. The distribution of endrin in the alluvial/unconfined groundwater flow system is illustrated on the plume map presented in Figure 4.2-4. Endrin was detected in confined Denver Formation groundwater within zones 1, 2, and 3. These detections are shown on the concentration point plots presented in Appendix D. The Unconfined Flow System aquifer plume map and Denver Formation point plots are discussed in Sections 4.2.3.2 and 4.2.3.3 below. Alluvial, unconfined Denver Formation and confined Denver Formation endrin detections are summarized in Table 4.2-5.

4.2.3.1 Historical Water Quality Data

Endrin is a chlorinated hydrocarbon insecticide that was produced at RMA between 1950 and 1965, and it occurred in aqueous effluent that was placed in RMA disposal basins between 1950 to 1965 (Ebasco, 1988, RIC#88357R01).

Historically, endrin has been detected in both the alluvial aquifer and the Denver Formation at RMA. Based on Initial Screening Program data, concentrations in excess of 1.0 ug/l were observed in alluvial groundwater immediately downgradient of Basin F

(Sections 23 and 26), adjacent to the north boundary (Section 24), and in the vicinity of the Section 36 lime settling ponds.

Endrin was detected in the uppermost aquifer between 1975 and 1985 in the South Plants area, and near Basins A, B, C, D, E and F to the Northwest Boundary Containment System and the North Boundary Containment System (MKE unpublished data, 1986). The highest concentrations of endrin in Denver Formation groundwater during the Initial Screening Program were detected in the vicinity of Basins C, D and F and immediately adjacent to the southwestern boundary of Basin F.

4.2.3.2 Unconfined Flow System

During Third Quarter FY87, 297 groundwater samples were collected from alluvial and unconfined Denver Formation wells and were analyzed for endrin. Of these, 262 samples were collected from wells screened within alluvium and 35 samples were collected from wells completed within the unconfined groundwater flow system in the uppermost Denver Formation. Endrin concentrations ranging from 0.064 to 1.51 ug/l were observed in 43 of the 297 groundwater samples analyzed. A summary of analytical results for endrin in Denver Formation wells completed within the Unconfined Flow System is presented in Table 4.2-7. The certified reporting limits used for endrin analyses during the Third Quarter FY87 were 0.05 and 0.06 ug/l. Concentrations in excess of 1.0 ug/l were observed between Basin F and the North Boundary Containment System (Sections 23 and 24) and immediately downgradient of the north boundary (Section 13).

Endrin was detected in samples collected from wells within unconfined portions of Denver Formation zones 1 and 2. A single endrin detection of 0.198 ug/l (Well 19003) was observed in zone 1. Within zone 2, endrin concentrations ranged from 0.115 (Well 23203) to 1.22 ug/l (Well 23253).

The distribution of endrin in the Unconfined Flow System is shown on the plume map in Figure 4.2-4. Two endrin plumes were identified; the largest extending in the Basin F pathway from Basin F to immediately downgradient of the north boundary, and a second extending in the Central pathway area from southeastern Section 27 to near the Northwest Boundary Containment System. In a third area (Basin A pathway, southwestern

Table 4.2-7 Summary of Analytical Results for Endrin for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm

Geologic Unit	No. of Samples Analyzed	No. of Detections	Range of Detection (ug/l) ¹	No. of Detections Above the Upper CRLs ²	Range of Detections Exceeding Upper CRLs ² (ug/l) ¹
ALLUVIUM	262	35	0.064 - 1.51	13	<0.120 - <1.50
DENVER					
B, Unconfined	0	0	--	0	--
B, Confined	3	0	--	1	<1.50
VC/VCE, Unconfined	7	0	--	0	--
VC/VCE, Confined	0	0	--	0	--
A, Unconfined	3	0	--	1	<0.30
A, Confined	28	0	--	2	<0.085 - <0.120
Iu, Unconfined	0	0	--	0	--
Iu, Confined	13	0	--	1	<0.185
1, Unconfined	8	1	0.198	1	<0.520
1, Confined	16	2	>0.057 - 0.062	0	--
2, Unconfined	13	7	0.115 - 1.220	0	--
2, Confined	28	1	0.058	1	<0.300
3, Unconfined	4	0	--	0	--
3, Confined	20	1	0.162	1	<0.180
4, Unconfined	0	0	--	0	--
4, Confined	19	0	--	1	<0.120
5, Confined	9	0	--	0	--
6, Confined	2	0	--	1	<0.085
7, Confined	2	0	--	0	--

¹ Micrograms per liter

² Certified Reporting Limits

Source: HLA, 1988.

Section 36), endrin may exist but its presence could not be confirmed due to dilution of samples and resulting high reporting limits. Historical data were therefore reviewed to assess the concentrations of endrin in this area. This review indicated the presence of endrin in Wells 36001, 36056 and 36076. This area is outlined on Figure 4.2-4.

Isolated detections of endrin were observed on-post in Sections 2, 22, 27 and 34 and off-post in Section 13. Elevated reporting limits occurred in isolated areas on-post in Sections 23, 26, 27 and 36 and off-post in Section 14.

The largest plume occurs in the Basin F pathway and is shown in Figure 4.2-4. This plume extends from Basin F to the North Boundary Containment System. A second plume then appears to occur a short distance downgradient of the RMA north boundary. Basin F may have provided a source of endrin identified within this area. The Basin F pathway plume trends northeast from Basin F for approximately 4,500 ft to west-central Section 24, shifts to a more northerly direction and continues for approximately 3,000 ft to the North Boundary Containment System.

Downgradient of the North Boundary Containment System the second plume trends northwest along a portion of the off-post First Creek pathway for a distance of approximately 2,500 ft in off-post Sections 13 and 14. Endrin concentrations are laterally much more extensive upgradient of the North Boundary Containment System than in the off-post area. Upgradient of the North Boundary Containment System, plume width ranges from 1,000 ft to approximately 3,000 ft. Downgradient of the North Boundary Containment System, plume width generally measures less than 500 ft. The endrin plume appears to spread laterally to the east and west in the area immediately upgradient of the North Boundary Containment System but is observed only within a narrow band downgradient of the system (Figure 4.2-4). This condition implies that the plume is generally contained by the North Boundary Containment System soil-bentonite barrier. Contaminant transport beneath the barrier through the Denver Formation is possible but endrin detected downgradient of the barrier may be representative of residual contamination. Contaminant trends in and around the North Boundary Containment System and Northwest Boundary Containment System will be discussed further in Task 36 (ESE, 1988c, RIC#88344R02), Task 25 (ESE, 1988f, RIC#89024R02) and Task 39 (ESE, 1988b, RIC#89024R01).

Endrin concentrations within the Basin F pathway - off-post area range from 0.076 to 1.51 ug/l with the highest detection reported for Well 37312 located adjacent to the north boundary in off-post Section 13. On-post, the highest detection observed within the plume was 1.47 ug/l in Well 24179 located upgradient and adjacent to the North Boundary Containment System. Although actual concentrations of endrin were not reported from many of the samples collected immediately downgradient of Basin F because of sample dilutions and elevated reporting limits, some Wells (i.e., 26041, 26008) have historically shown endrin concentrations in excess of method detection limits and were thus included within the contours shown in Figure 4.2-4.

A second plume of endrin shown in Figure 4.2-4, occurs in the Central pathway area and trends northwest from southeastern Section 27 to south-central Section 22. In terms of lateral extent and reported concentrations, this plume is much smaller than the plume previously discussed near Basin F. This plume measures approximately 5,300 ft in length and from about 200 to 600 ft in width. Endrin concentrations within the plume range from 0.154 to 0.329 ug/l. The southeastern portion of this plume is largely contained within a narrow paleochannel that originates in the vicinity of Basin A Neck and extends beneath Basins B, C, D and E.

A third area of elevated levels of endrin occurs in the Basin A pathway, and is shown in Figure 4.2-4. This was inferred to represent a plume in the southwestern quadrant of Section 36. This plume was inferred based on historical endrin concentrations detected in the three wells shown within the contour. Elevated reporting limits for endrin were reported for Wells 36056 and 36076 during Third Quarter FY87. Dilution of the sample collected from Well 36056 was most likely attributed to the presence of dieldrin detected at a concentration of 2.34 ug/l. Dilution of the sample from Well 36076, however, cannot be attributed to any of the targeted chlorinated pesticides and probably resulted from the presence of other target or nontarget analytes. Well 36001 shows a historical trend of elevated endrin. The below-detection report for this well is anomalous relative to the historical trend and the well was thus included in the inferred plume. Furthermore, the proximity of the plume to potential source areas such as the South Plants area, Section 36 lime settling ponds and Basin A also supports the inference of endrin occurrence in this area.

4.2.3.3 Denver Aquifer

During Third Quarter FY87, 175 groundwater samples from Denver Formation wells were analyzed for endrin. Of these, 35 Denver Formation wells were completed within the Unconfined Flow System. The analytical results from these 35 wells are summarized on Table 4.2-7. These results were contoured and discussed in conjunction with the saturated alluvium in the preceding section. The results of endrin analyses performed on samples collected from the remaining 140 confined Denver Formation wells are also summarized on Table 4.2-7.

Based on Third Quarter FY87 analytical results, endrin concentrations above certified reporting limits were observed in samples collected from confined Denver Formation wells completed only within zones 1, 2 and 3 (Table 4.2-7). The locations of wells completed within each of these zones and endrin concentrations are shown on the point plot maps in Appendix D. The contamination noted in confined Denver Formation zone 1, in Wells 26057 and 26140, shows no clear relationship to alluvial contamination. Contamination, however, may be related to wastewater disposal in Basin C or to leakage from the chemical sewer near the well. These features were identified by MKE (1986 unpublished data) as possible sources of endrin contamination. The endrin detection noted in Well 23218 in Denver Formation zone 2 and subcrop area shows a possible relationship to contamination in the overlying Unconfined Flow System. The endrin detection noted in Well 26142 in Denver Formation zone 3 shows a possible relationship to contamination in the overlying Zone 1 (Well 26140).

Endrin was not detected in groundwater samples obtained from wells screened in the confined portions of the remaining Denver Formation zones. The locations of wells within these zones are shown on the well location maps in Appendix D. Well 27054 is the only well shown on these maps that was not sampled for endrin analysis. This well is screened within zone 4.

4.2.4 Dithiane and Oxathiane

Analyses for the compounds dithiane and oxathiane were performed on 407 groundwater samples collected from alluvial and Denver Formation wells during Third Quarter FY87. Because these compounds are similar in chemical structure, physical properties and origin,

composite maps of the distribution of these two compounds were prepared for presentation. Composite concentrations were calculated by summing detected concentrations of dithiane and oxathiane at each well, with concentrations below certified reporting limits set equal to zero. Composite concentrations ranging from 1.25 to 9,310 ug/l were detected in 64 of the 407 samples analyzed.

The distribution of combined dithiane/oxathiane in the Unconfined Flow System is illustrated on the plume map in Figure 4.2-5. Individual compound oxathiane and dithiane plume maps are included in Appendix D. The lowest contour shown on this map corresponds to the highest certified reporting limit used during analyses for these compounds (3.30 ug/l).

Dithiane/oxathiane were detected in confined Denver Formation groundwater only within zones 1u, 1, 2 and 4. These detections are shown on the concentration point plots in Appendix D. The Unconfined Flow System plume map and Denver Formation point plots are discussed in Sections 4.2.4.2 and 4.2.4.3 below. Alluvial, unconfined Denver Formation, and confined Denver Formation oxathiane/dithiane detections are summarized in Table 4.2-5.

4.2.4.1 Historical Water Quality Data

Dithiane and oxathiane are decomposition by-products in the manufacture of mustard gas (Ebasco, 1988b, RIC#88357R01).

Historically, dithiane and oxathiane have been detected in both alluvial and Denver Formation groundwater at RMA. Distributions of these compounds in the alluvial aquifer have historically been observed in the vicinity of Basins A through F and extending north from Basin F to the RMA north boundary (Final Initial Screening Program Report, ESE, 1987a, RIC#87253R01). During the Initial Screening Program, dithiane and oxathiane were detected in Denver Formation groundwater in the vicinity of Basins B, C and D in northern Section 35 and southern Section 26. Groundwater quality data obtained between 1974 and 1985 indicated that dithiane and oxathiane were detected in the Denver aquifer in the vicinity of Basins C, D and E, north-northeast of Basin F, near the North Boundary Containment System, and in isolated areas in Section 36.

4.2.4.2 Unconfined Flow System

During Third Quarter FY87, 268 groundwater samples were collected from alluvial and unconfined Denver Formation wells and were analyzed for dithiane/oxathiane. Of these, 233 samples were collected from wells screened within the alluvium and 35 samples were collected from wells completed within the Unconfined Flow System in the uppermost Denver Formation. Dithiane/oxathiane concentrations ranging from 1.25 to 9,310 ug/l were observed in 58 of the 268 groundwater samples analyzed. A summary of analytical results for composite dithiane/oxathiane in alluvial and Denver Formation wells completed within the unconfined groundwater flow system is presented in Table 4.2-8. The certified reporting limits used for dithiane analyses during Third Quarter FY87 were 1.10, 1.59, and 3.34 ug/l. The certified reporting limits for oxathiane during Third Quarter FY87 were 1.35 and 2.00 ug/l.

The distribution of dithiane/oxathiane in the Unconfined Flow System is shown on the plume map in Figure 4.2-5. An apparently continuous dithiane/oxathiane plume was identified extending from the South Plants-Basin A pathway through the Basin F east-Basin F pathways to the North Boundary Containment System. The plume also appears to exhibit an occurrence off-post along the First Creek off-post pathway. This plume area consists of three primary components: (1) a southern component extending from the northern portion of Section 1 through the Basin A pathway and along the Basin A neck pathway to southwestern section 26, (2) a northern component extending north along the Basin F pathway to the North Boundary Containment System and (3) an off-post component extending from the North Boundary Containment System along the First Creek off-post pathway to central Section 14. Continuity of the plume between the southern and northern components through Basin C is based on historical dithiane/ oxathiane data.

As shown in Figure 4.2-5, isolated detections of dithiane/oxathiane were noted on-post in Sections 23, 27 and 36 and off-post in Section 13. All isolated detections occurred at concentrations lower than the highest certified reporting limit that was used to define the minimum contour, and therefore, were not mapped.

Table 4.2-8 Summary of Analytical Results for Composite Dithiane/Oxathiane for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm

Geologic Unit	No. of Samples Analyzed	No. of Detections	Range of Detection (ug/l) ¹	No. of EDLs [*]	Range of EDLs (ug/l) ¹
ALLUVIUM	232	47	1.25 - 567	1	<1.76
DENVER					
B, Unconfined	0	0	--	0	--
B, Confined	3	0	--	0	--
VC/VCE, Unconfined	7	2	2,280 - 9,310	0	--
VC/VCE, Confined	0	0	--	0	--
A, Unconfined	3	1	361	0	--
A, Confined	28	0	--	0	--
1u, Unconfined	0	0	--	0	--
1u, Confined	13	1	200	0	--
1, Unconfined	8	3	1.79 - 54.1	0	--
1, Confined	16	2	27.0 - 312	0	--
2, Unconfined	13	5	3.16 - 45.1	0	--
2, Confined	28	2	21.5 - 102	0	--
3, Unconfined	4	0	--	0	--
3, Confined	20	0	--	0	--
4, Unconfined	0	0	--	0	--
4, Confined	19	1	1.68	0	--
5, Confined	9	0	--	0	--
6, Confined	2	0	--	0	--
7, Confined	2	0	--	0	--

¹ Microgram per liter
^{*} Elevated detection limits

Source: HLA, 1988.

The southern component of the dithiane/oxathiane plume shown in Figure 4.2-5 extends approximately 11,000 ft from the South Plants through Basin A, and along the Basin A Neck pathway to southwestern Section 26. Through these areas, the plume ranges in width from approximately 1,500 ft in Basin A Neck to nearly 3,000 ft in Basin A. Concentrations within this portion of the plume range from 56.8 to 9310 ug/l with concentrations greater than 500 ug/l present over the majority of Basin A. The general South Plants/Basin A area was a possible source for this plume.

The northern component of the dithiane/oxathiane plume extends approximately 8,000 ft from south of Basin F to the North Boundary Containment System along the Basin F pathway. Along this pathway, the plume ranges in width from approximately 1,500 ft at the North Boundary Containment System to approximately 3,000 ft downgradient of Basin F in Section 23. Dithiane/oxathiane concentrations in this area range from 1.68 to 113 ug/l, with the highest concentration noted in Well 23049 located approximately 1,000 ft north-northeast of Basin F. Dithiane/oxathiane concentrations in excess of 50 ug/l extend approximately 5,000 ft to the north from just south of Basin F, and are observed to bifurcate around a bedrock high in central Section 23. A possible source area within the northern component of the dithiane/oxathiane plume was Basin F. The Basin F plume occurs primarily in areas of saturated alluvium, except apparently under Basin F (Figure 4.2-5).

The off-post component of the dithiane/oxathiane plume extends approximately 2,500 ft from the North Boundary Containment System along the First Creek off-post pathway to central Section 14. Along this component, the plume is generally less than 750 ft in width. Dithiane/oxathiane concentrations detected within the plume in this area range from 6.48 to 24.4 ug/l.

The dithiane/oxathiane plume is laterally more extensive and contains higher concentrations upgradient of the North Boundary Containment System than that in the off-post area. In addition, the plume appears to spread laterally to the east and west in the area immediately upgradient of the North Boundary Containment System but is observed within two narrow bands downgradient of the system (Figure 4.2-5). This distribution implies that, in general, the plume is contained by the North Boundary Containment System soil-bentonite barrier. Dithiane/oxathiane have been detected downgradient of the system. These detections may be a result of minor transport beneath

the barrier, but are probably more representative of residual contamination left prior to the installation of the North Boundary Containment System. Contaminant trends in and around the North Boundary Containment System and Northwest Boundary Containment System will be discussed further in Task 36 (ESE, 1988e, RIC#88344R02), Task 25 (ESE, 1988f, RIC#89024R02) and Task 39 (ESE, 1989b, RIC#89024R01).

4.2.4.3 Denver Aquifer

During Third Quarter FY87, 175 groundwater samples from Denver Formation wells were analyzed for dithiane/oxathiane. Thirty-five of these Denver Formation wells were completed within the Unconfined Flow System. The analytical results from these 35 wells are summarized on Table 4.2-8. These results were contoured and discussed in conjunction with the saturated alluvium in the preceding section. The results of dithiane/oxathiane analyses performed on samples collected from the remaining 140 confined Denver Formation wells are summarized on Table 4.2-8.

Based on Third Quarter FY87 analytical results, dithiane/oxathiane composite concentrations above certified reporting limits were observed in samples collected from confined Denver Formation wells completed only within the 1u, 1, 2 and 4 zones (Table 4.2-8). The locations of wells completed within each of these zones and detected dithiane/oxathiane concentrations are shown on the point plots in Appendix D.

A single detection of dithiane/oxathiane was observed in zone 1u of the confined Denver Formation at Well 35016. A composite dithiane/oxathiane concentration of 200 ug/l was noted in the groundwater sample from this well. The well is located within the Basin A neck pathway but separated stratigraphically from the Unconfined Flow System by the zone A of the Denver Formation.

Two detections of dithiane/oxathiane were noted in confined Denver Formation zone 1 and are shown in Figure 4.2-6. Wells 26066 and 26086, located in the vicinity of Basin C, recorded detections of 312 and 27.0 ug/l respectively. Well 26066 is located within the area of subcrop of zone 1 (Figure 4.2-6) and, therefore, may be related to dithiane/oxathiane contamination identified in the Unconfined Flow System in this area. The detection in Well 26086 shows no clear relationship to overlying contamination.

Concentrations of 21.5 and 102 ug/l were detected in confined Denver Formation zone 2, in Wells 26061 and 26129 respectively. Detections in the Denver Formation zone 2 probably are related to detections in overlying Denver zones or in the Unconfined Flow System.

A single detection of dithiane/oxathiane was observed in the confined Denver Formation zone 4 at Well 23193. A composite dithiane/oxathiane concentration of 1.68 ug/l was noted in the well. This well is located within the Basin F north pathway but separated stratigraphically from the Unconfined Flow System by Denver Formation zones 1, 2 and 3. A direct relation between contamination in the uppermost aquifer and the observed detection in Well 23193 is not readily apparent.

4.2.5 Benzothiazole

Analyses for benzothiazole were performed on 406 groundwater samples collected from alluvial and Denver Formation wells during Third Quarter FY87. Benzothiazole concentrations ranging from 1.24 to 14.6 ug/l were detected in 21 of the 408 samples analyzed. The distribution of benzothiazole in the Unconfined Flow System is illustrated on the plume map presented in Figure 4.2-7. Benzothiazole was detected in confined Denver Formation groundwater only within zones 1u, 1, 4 and 5. These detections are shown on the concentration point plots presented in Appendix D. The Unconfined Flow System plume map and Denver Formation point plots are discussed in Sections 4.2.5.2 and 4.2.5.3 below. Alluvial, unconfined Denver Formation, and confined Denver Formation benzothiazole detections are summarized in Table 4.2-5.

4.2.5.1 Historical Water Quality Data

Benzothiazole is a heterocyclic aromatic organosulfur compound associated with the manufacture of pesticides (Ebasco, 1988b, RIC#88357R01). Historically, analyses for the compound benzothiazole were not performed on RMA groundwater samples. However, benzothiazole was recognized as a possible contaminant in RMA groundwater and subsequently was added to the RMA target analyte list during Second Quarter FY87 (Winter of 1987).

Comparisons of WRI benzothiazole analytical results to Initial Screening Program analytical results cannot be made because benzothiazole is a comparatively new target analyte that was not included in the Initial Screening Program list of analytical parameters.

4.2.5.2 Unconfined Flow System

During Third Quarter FY87, 267 groundwater samples were collected from alluvial/unconfined wells and were analyzed for benzothiazole. Of these, 231 samples were collected from wells screened within the alluvium and 35 samples were collected from wells completed within the Unconfined Flow System in the uppermost Denver Formation. Benzothiazole concentrations ranging from 1.24 to 14.6 ug/l were observed in 17 of the 266 groundwater samples analyzed. A summary of analytical results for benzothiazole in alluvial and Denver Formation wells completed within the Unconfined Flow System is presented in Table 4.2-9.

The certified reporting limits used for benzothiazole analyses during the Third Quarter were 1.14 and 2.00 ug/l. Concentrations in excess of 5.00 ug/l were observed in Basin A (Section 36) and northeast of Basin F in Section 23.

The distribution of benzothiazole in the Unconfined Flow System is shown on the plume map in Figure 4.2-7. Two benzothiazole plumes were identified; the first in Section 23, extending from approximately 2,000 ft northeast of Basin F in the Basin F pathway toward the North Boundary Containment System, and a second in the vicinity of Basin A in Section 36 (Basin A pathway). Several isolated detections of benzothiazole were noted in Sections 23, 24, 26, 35 and 36. The majority of these isolated occurrences showed concentrations between the two method detection limits, thus fall outside the lowest contour interval. However, an isolated concentration of 7.73 ug/l was noted in Well 36076, located in the southern portion of Basin A. An elevated reporting limit resulting from sample dilution was observed in Well 26041.

The plume shown in Section 23, Figure 4.2-7 trends generally north-northeast along the Basin F northern pathway for a distance of approximately 3,000 feet. A localized variation in the general trend of the plume is noted along the plume's eastern margin.

Table 4.2-9 Summary of Analytical Results for Benzothiazole for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm

Geologic Unit	No. of Samples Analyzed	No. of Detections	Range of Detection (ug/l) ¹	No. of EDLs [*]	Range of EDLs (ug/l) ¹
ALLUVIUM	231	13	1.24 - 12.8	0	--
DENVER					
B, Unconfined	0	0	--	0	--
B, Confined	1	0	--	0	--
1, Unconfined	1	1	14.6	0	--
1, Confined	0	0	--	0	--
2, Unconfined	3	1	6.79	0	--
2, Confined	23	0	--	0	--
3, Unconfined	0	0	--	0	--
3, Confined	13	1	3.56	0	--
4, Unconfined	8	0	--	1	<40.0
4, Confined	16	1	1.62	0	--
5, Unconfined	13	2	5.01 - 6.62	0	--
5, Confined	23	0	--	0	--
6, Unconfined	1	0	--	0	--
6, Confined	20	0	--	0	--
7, Unconfined	0	0	--	0	--
7, Confined	19	1	2.34	0	--
8, Confined	9	1	1.50	0	--
9, Confined	2	0	--	0	--
10, Confined	2	0	--	0	--

¹ Micrograms per liter
^{*} Elevated detection limits

Source: HLA, 1988.

Concentrations within the plume range from 3.64 to 12.8 ug/l. Benzothiazole concentrations in excess of 5.00 ug/l were present within the central portion of the plume. The isolated detections noted in Sections 23 and 24 are probably related to this plume but all occur at concentrations below 2.00 ug/l and, therefore, were not contoured.

Downgradient of the North Boundary Containment System, an isolated benzothiazole detection was noted in Well 24161. This detection is probably related to the plume identified in Section 23 and may have been representative of residual contamination or minor transport beneath the North Boundary Containment System through the Denver Formation. Groundwater flow and contaminant transport beneath the North Boundary Containment System barrier probably occurs at a reduced velocity due to lower hydraulic conductivity of the Denver Formation bedrock. Contaminant trends in and around the North Boundary Containment System and Northwest Boundary Containment System will be discussed further in Task 36 (ESE, 1988e, RIC#88344R02), Task 25 (ESE, 1988f, RIC#89024R02) and Task 39 (ESE, 1989b, RIC#89024R01).

The second plume shown in Figure 4.2-7 trends generally northwest and extends approximately 3,000 ft along the northeast margin of Basin A. Concentrations of benzothiazole in samples from the two wells that define the plume were 5.27 and 14.6 ug/l. Well 36090 completed in the Denver Formation VC/VCE zone had the highest observed Third Quarter FY87 benzothiazole detection at 14.6 ug/l. A possible source for this plume is the Basin A area.

Three isolated benzothiazole detections were noted at Wells 26006, 35023, and 36076. Probable sources for the contamination in Well 26006 included Basins B, C, and D. The generalized South Plants and Basin A areas were the probable sources for the benzothiazole detections noted in Wells 35023 and 36076.

4.2.5.3 Denver Aquifer

During the Third Quarter FY87, 174 groundwater samples from Denver Formation wells and were analyzed for benzothiazole. Thirty-five of these Denver Formation wells were completed within the Unconfined Flow System. The analytical results from these 35 wells are summarized in Table 4.2-9. These results were contoured and discussed in conjunction with the saturated alluvium in the preceding section. The results of benzothiazole

analyses performed on samples collected from the remaining 140 confined Denver Formation wells are also summarized on Table 4.2-9.

Based on Third Quarter FY87 analytical results, benzothiazole concentrations above certified reporting limits were observed in samples collected from confined Denver Formation wells completed only within confined Denver Formation zones 1u, 1, 4 and 5 (Table 4.2-9). The locations of wells completed within each of these zones and detected benzothiazole concentrations are shown on the point plots in Appendix D.

The highest benzothiazole concentration reported in confined Denver Formation wells during the Third Quarter FY87 (3.56 ug/l) was noted within the Denver Formation zone 1u in Well 35016. This well is located in the Basin A Neck area near the 1u zone subcrop. This benzothiazole detection may be related to benzothiazole contamination identified within the overlying Unconfined Flow System in Basin A.

Benzothiazole contamination in the Denver Formation 1 zone was noted near the eastern margin of Basin C in Well 26086. Unconfined Flow System samples in the immediate area reported no benzothiazole detections; therefore, the source for this contamination is not known.

Benzothiazole concentrations above method detection limits were observed in Denver Formation zones 4 and 5 at Wells 03004 and 04008, respectively. Upgradient benzothiazole contamination was not noted in the Unconfined Flow System, but benzothiazole was reported in surface water samples from Section 11. No definitive relationship between known source areas and benzothiazole contamination in the deeper confined Denver Formation can be inferred.

4.2.6 Organosulfur Compounds (chlorophenylmethyl sulfide, chlorophenylmethyl sulfoxide, and chlorophenylmethyl sulfone)

Analyses for one or more of the organosulfur compounds chlorophenylmethyl sulfide, chlorophenylmethyl sulfoxide and chlorophenylmethyl sulfone were performed on 406 groundwater samples collected from alluvial and Denver Formation wells during the Third Quarter FY87. Because these compounds are structurally related and have similar chemical and physical properties, composite maps of the distribution of these three compounds were

prepared for presentation. Composite concentrations were calculated by summing detected concentrations of chlorophenylmethyl sulfide, chlorophenylmethyl sulfoxide and chlorophenylmethyl sulfone at each well, with concentrations below certified reporting limits equal to zero. Composite concentrations ranging from 1.25 to 2054 ug/l were detected in 96 of the 406 samples analyzed.

The distribution of organosulfur compounds in the Unconfined Flow System is illustrated on the plume map presented in Figure 4.2-8. The lowest contour shown on this map corresponds to the highest detection limit used during analyses for these compounds (4.70 ug/l). One or more of the organosulfur compounds were detected in confined Denver Formation groundwater only within zones A, 1u, 1 and 2. These detections are shown on the concentration point plots presented in Appendix D. The Unconfined Flow System plume map and Denver Formation point plots are discussed in Sections 4.2.6.2 and 4.2.6.3 below. Alluvial, unconfined Denver Formation, and confined Denver Formation combined chlorophenylmethyl sulfide, chlorophenylmethyl sulfoxide and chlorophenylmethyl sulfone detections are summarized in Table 4.2-5.

4.2.6.1 Historical Water Quality Data

Both chlorophenylmethyl sulfide and chlorophenylmethyl sulfone are process intermediates generated during Planavin (a herbicide) manufacture. Chlorophenylmethyl sulfoxide is a decomposition product associated with Planavin manufacture (Ebasco, 1988b, RIC#88357R01). Historically, the organosulfur compounds chlorophenylmethyl sulfide, chlorophenylmethyl sulfoxide and chlorophenylmethyl sulfone have been detected in both alluvial and Denver Formation groundwater at RMA. During the Task 4 Initial Screening Program, one or more of these compounds were detected in 44 of 292 groundwater samples collected and analyzed, including 35 of 150 alluvial groundwater samples and 9 of 142 Denver Formation groundwater samples. Total concentrations of these organosulfur compounds ranged from 4.54 to 815 ug/l in alluvial groundwater and from 10.0 to 94.9 ug/l in Denver Formation groundwater. The distributions of total organosulfur compounds identified during the Initial Screening Program confirm general historical distribution trends identified based on analytical data generated prior to the Initial Screening Program. These earlier data include the USATHAMA database and data presented in the Spaine Report (1984, RIC#85133R04). In terms of individual compounds, chlorophenylmethyl

sulfone has historically been observed more frequently and in higher concentrations than either chlorophenylmethyl sulfide or chlorophenylmethyl sulfoxide.

In general, the areal distribution of organosulfur compounds detected in the alluvial groundwater system during the Initial Screening Program indicated an association with several of the recognized source areas at RMA, including the South Plants area, Basin A and Basins B through F. Total concentrations of these compounds generally ranged from 10 to 100 ug/l or greater in these areas. These compounds were also observed in the alluvial groundwater system in excess of 10 ug/l along the north boundary of RMA (Sections 23 and 24).

The distribution of the organosulfur compounds in the Denver groundwater system was primarily confined to the vicinity of Basins B, C and D in Section 26 and the northern portion of Section 35. Total concentrations of these compounds generally ranged from 1.3 to 10.0 ug/l in this area. The highest concentrations of these compounds were observed in isolated wells located in Section 2 (48 ug/l) and Section 26 (63.5 ug/l).

4.2.6.2 Unconfined Flow System

During Third Quarter FY87, 266 groundwater samples were collected from alluvial and unconfined Denver Formation wells and were analyzed for the organosulfur compounds chlorophenylmethyl sulfide, chlorophenylmethyl sulfoxide and chlorophenylmethyl sulfone. Of these, 231 samples were collected from wells screened within alluvium and 35 samples were collected from wells completed within the Unconfined Flow System in the uppermost Denver Formation. Total concentrations of these compounds ranging from 2.16 to 2054 ug/l were observed in 89 of the 266 groundwater samples analyzed. A summary of analytical results for the composited and individual organosulfur compounds in alluvial and Denver Formation wells completed within the unconfined groundwater flow system are presented in Table 4.2-10. The certified reporting limits used for these organosulfur analyses during Third Quarter FY87 were 1.08 and 1.30 ug/l for chlorophenylmethyl sulfide, 1.98 and 4.20 ug/l for chlorophenylmethyl sulfoxide, and 2.24 and 4.70 ug/l for chlorophenylmethyl sulfone.

Table 4.2-10 Summary of Analytical Results for Composite Organosulfurs for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm

Geologic Unit	No. of Samples Analyzed	No. of Detections	Range of Detection (ug/l) ¹	No. of EDLs*	Range of EDLs (ug/l) ¹
ALLUVIUM	231	74	2.16 - 2054	0	--
DENVER					
B, Unconfined	0	0	--	0	--
B, Confined	3	0	--	0	--
VC/VCE, Unconfined	7	3	8.46 - 456	0	--
VC/VCE, Confined	0	0	--	0	--
A, Unconfined	3	1	3.79	0	--
A, Confined	28	3	3.64 - 4.09	0	--
1u, Unconfined	0	0	--	0	--
1u, Confined	13	2	1.25 - 3.16	0	--
1, Unconfined	8	3	5.81 - 510	0	--
1, Confined	16	1	2.50	0	--
2, Unconfined	13	7	11.3 - 614	0	--
2, Confined	28	1	11.93	0	--
3, Unconfined	4	0	--	0	--
3, Confined	20	0	--	0	--
4, Unconfined	0	0	--	0	--
4, Confined	19	0	--	0	--
5, Confined	9	0	--	0	--
6, Confined	2	0	--	0	--
7, Confined	2	0	--	0	--

¹ Micrograms per liter
* Elevated detection limit

Source: ESE, 1988.

Data indicate that chlorophenylmethyl sulfone was detected more frequently and in higher concentrations than chlorophenylmethyl sulfide and chlorophenylmethyl sulfoxide in the Unconfined Flow System flow system during Third Quarter FY87. As a result, the distribution of total organosulfur compounds in the Unconfined Flow System, discussed below, is influenced more by chlorophenylmethyl sulfone than by the other two organosulfur compounds. Plume maps illustrating the distribution of each organosulfur compound in the Unconfined Flow System are included in Appendix D. Comparison of these maps indicates that, in general, the distribution of chlorophenylmethyl sulfide, chlorophenylmethyl sulfoxide and chlorophenylmethyl sulfone are similar, occurring primarily in the South Plants/Basin A area and from the Basin F area to the northern off-post area.

The distribution of organosulfur compounds in the Unconfined Flow System is shown on the plume map presented in Figure 4.2-8. Two organosulfur plume areas were identified. The largest occurs in the Basin F pathway extending from Basin F to the North Boundary Containment System and also occurs off-post north and northwest from the northern RMA boundary. A second plume area extends from the South Plants/Basin A pathway along the Basin A Neck pathway to east central Section 27.

The largest plume shown in Figure 4.2-8 trends north-northeast from Basin F and extends approximately 7,500 ft to the North Boundary Containment System. A plume also occurs downgradient of the North Boundary Containment System, extending approximately 8,000 ft along the off-post northern pathway and approximately 3,000 ft along the off-post First Creek pathway. The width of the plumes range from approximately 2,500 to 4,500 ft on-post and from approximately 700 to 1,600 ft off-post. Total organosulfur concentrations within the plumes range from 6.24 to 2054 ug/l on-post and from 5.20 to 157 ug/l off-post. The highest on-post concentration was noted in Well 26133, located approximately 600 ft northeast of Basin F. The highest off-post concentration was noted in Well 37391, located approximately 2,500 ft north of the RMA boundary in west-central Section 13. The Basin F area was considered a possible source for the organosulfur compounds identified in this location.

Comparison of on-post and off-post occurrences indicates that the plumes are laterally more extensive and generally contain higher organosulfur concentrations on-post than off-post. Immediately upgradient of the North Boundary Containment System, the plume

extends approximately 3,500 ft along the soil-bentonite barrier, while downgradient of the system the plume narrows to a width of about 1,600 ft. Organosulfur concentrations noted in wells immediately downgradient of the North Boundary Containment System are generally lower than those observed in upgradient wells. However, approximately 3,000 ft north of the North Boundary Containment System, the organosulfur concentrations are similar to concentrations observed upgradient of the North Boundary Containment System. The relatively high concentrations detected further downgradient of the North Boundary Containment System in Sections 12 and 13 are possibly a remnant high-concentration "slug" that was isolated from the on-post plume by activity of the North Boundary Containment System.

The second plume of organosulfur compounds shown in Figure 4.2-8 trends north-northwest from the South Plants/Basin A area along the Basin A Neck pathway to east-central Section 27. The plume extends approximately 13,000 ft in length and ranges from 300 to 3,400 ft in width. Total organosulfur concentrations within the plume range from 5.98 to 1,421 ug/l. The highest concentration within the plume was noted in Well 36076, located in the southwest corner of Section 36 near the lime settling ponds. The sources for this plume appear to have been the South Plants area, and Basins A, B and D. In general, organosulfur concentrations within this second plume are lower than those within the Basin F - off-post pathways previously discussed.

Isolated detections of the organosulfur compounds were noted during Third Quarter FY87 monitoring event in Sections 2, 23, 24, 27 and 34, and in the northern off-post area (Figure 4.2-8). These isolated detections, except for those noted in Wells 02008 (5.73 ug/l) and 27062 (4.85 ug/l), occurred at concentrations below the lowest contour interval (4.70 ug/l) and therefore, were not considered for mapping. The organosulfur contamination noted in Well 02008 may have been a result of contaminant migration from the South Plants area. The isolated detection observed in Well 27062 is most likely related to the organosulfur contamination that has been identified within the Basin A Neck pathway. The remaining isolated detections shown in Figure 4.2-8 occur in the vicinity of identified organosulfur plumes; except for the detection in Well 34002 (3.79 ug/l) which does not appear to be related to identified organosulfur contamination or known source areas.

4.2.6.3 Denver Aquifer

During Third Quarter FY87, 175 groundwater samples were collected from Denver Formation wells and were analyzed for one or more of the organosulfur compounds. Thirty-five of these samples were collected from Denver Formation wells completed within the Unconfined Flow System. The analytical results for these 35 samples are summarized on Table 4.2-10. These results were contoured and discussed in conjunction with the saturated alluvium in the preceding section. The results of individual and composited organosulfur analyses performed on samples collected from the remaining 140 confined Denver Formation wells are summarized on Table 4.2-10. Data indicate that chlorophenylmethyl sulfoxide was not detected in any of the 140 samples collected from confined Denver Formation wells.

Based on Third Quarter FY87 analytical results, organosulfur concentrations above certified reporting limits were observed in samples collected from confined Denver Formation wells completed only within the zones A, 1u, 1 and 2 (Table 4.2-10). The locations of wells completed within each of these zones and detected organosulfur concentrations are shown on the point plot maps presented in Appendix D.

The three detections of combined organosulfur compound concentrations observed within the confined Denver Formation Zone A occurred in Wells 02035, 35066, and 36110 (Appendix D). All of these wells are located within the zone A subcrop. The contamination noted in these wells possibly relates to contamination identified in the overlying Unconfined Flow System. Two detections of combined organosulfur compound concentrations were noted within the confined Denver Formation zone 1u in Wells 02025 and 35016. The source for the contamination noted in Well 02025 is not known but this detection may be related to the organosulfur contamination identified within overlying zone A in nearby Well 02035. Well 35016 is located near the zone 1u subcrop in northeastern Section 35. The contamination in this well is probably related to contamination identified within the overlying Basin A Neck pathway.

Organosulfur compounds were noted in both zones 1 and 2 (Appendix D). The organosulfur contamination generally was detected beneath Basins C, D and E. Contamination probably is associated with contamination in the overlying Unconfined Flow System.

4.2.7 Volatile Aromatic Organics Compounds

Analyses for these compounds were conducted for a total of 471 samples collected during the Third Quarter FY87, 297 of which were collected from the alluvium, 141 from the Denver, and 35 from the unconfined portion of the Denver. The volatile aromatic organics include benzene, chlorobenzene, toluene, ethylbenzene, meta-xylene, and ortho- and para-xylenes. Chlorobenzene may also be considered an halogenated organic, but was included in this group because of its aromatic structure and similar chemical behavior. Composite concentrations were calculated by summing the detected volatile aromatic organic concentrations at each well, with concentrations below the certified reporting limits equal to zero. Composite concentrations ranged from 1.39 ug/l to 56,200 ug/l.

A composite volatile aromatic organics map was prepared for the Unconfined Flow System to provide a comprehensive understanding of the distribution of this compound group in RMA alluvial groundwater Figure 4.2-9. The highest certified reporting limit of 2.47 ug/l is the lowest contour interval on this figure. As previously stated, data from unconfined Denver wells were included with alluvial plume maps to provide a better understanding of contamination in the Unconfined Flow System. The following section is a discussion of volatile aromatic organics occurrences in the Unconfined Flow System and confined Denver Formation groundwater, followed by discussions of benzene and chlorobenzene distribution. These two compounds are presented because chlorobenzene and benzene are the most commonly detected volatile aromatic organics within both the alluvium and Denver and exert the most influence over the total volatile aromatic organics plume configuration. The occurrence of volatile aromatic organics within the Denver Formation will also be presented with detailed descriptions of Denver Formation benzene and chlorobenzene occurrence included under the individual compound discussions in Sections 4.2.7.2 and 4.2.7.3. Alluvial, unconfined Denver Formation and confined Denver Formation detections for individual volatile aromatic organics are summarized in Table 4.2-5.

4.2.7.1 Total Volatile Aromatic Organic Compounds

Volatile aromatic organics are presented as a group in order to provide an overview of their occurrence in RMA groundwater. Historical volatile aromatic organics distribution is discussed first, followed by discussions of volatile aromatic organics occurrences in both

the Unconfined Flow System and Denver Formation aquifers. Volatile aromatic organics plumes within the Unconfined Flow System are shown in Figure 4.2-9, and Denver Formation point plot maps are presented in Appendix D.

Historical Water Quality Data

Historical information for the volatile aromatic organics acquired prior to 1985 is quite scarce because early analytical programs did not include volatile aromatic organics in analytical studies. Historical compound distribution maps provided by MKE (unpublished data, 1986) indicates occurrences of benzene and toluene in excess of 1,000 ug/l in the South Plants area that extend to the west-southwest through Section 2 (Figure 4.2-9). These occurrences were also identified northward through Basin A and into the Basin A Neck area. Denver Formation volatile aromatic organics occurrences from Initial Screening Program data were also plotted on these distribution maps, and the data indicate that the Denver Formation contains detections of volatile aromatic organics in Sections 2, 22, 23 and 24.

The Initial Screening Program report (ESE, 1987a, RIC#87253R01) provided alluvial and Denver volatile aromatic organics distribution plots constructed from data collected during the September 1985 to March 1986 time period. These maps indicate the presence of toluene, benzene, ethylbenzene and xylene in alluvial groundwater in excess of 1,000 ug/l in the South Plants - Basin A area and north-northeast of Basin F through Section 23. Denver Formation volatile aromatic organic detections in excess of 10 ug/l, occurred in Sections 1, 22, 23, 26 and 35 with isolated, relatively low level detections in Sections 2, 3, 4, 6, 19, 25 and 32.

Unconfined Flow System

During the Third Quarter FY87, analysis for volatile aromatic organics were conducted on 296 alluvial and 35 unconfined wells, with 49 wells containing detectable concentrations of volatile aromatic organics. Detected concentrations ranged from 1.39 to 56,200 ug/l.

Volatile aromatic organics occur in Unconfined Flow System in the South Plants - Basin A area to the Basin A Neck pathway; and the Basin F, Off-Post Northern, First Creek and Quincy Street pathways (Figures 4.2-1 and 4.2-9). Isolated detections occur in the north and northwestern off-post areas and in on-post Sections 4, 6, 7, 22, 23, 24 and 26. This

section describes Unconfined Flow System volatile aromatic organic plume occurrences within each pathway.

The volatile aromatic organics plume in the Basin A-South Plants pathway area, as determined from Third Quarter data, extends from the northern portion of Section 1 through the western portion of Section 36 (Figure 4.2-9). Concentrations of volatile aromatic organics within this plume range from 2.49 ug/l (Well 36065) to 56,200 ug/l (Well 36001). This area extends northward and includes unconfined Well 36056. A second, relatively high concentration of total volatile aromatic organics occurs around Well 36090 (55.9 ug/l), with apparent total concentration in the entire plume dropping to less than 10 ug/l through the Basin A Neck area. The plume concentration decreases to below the certified reporting limits northwest in the Basin A Neck. The mapped plume is over 8,000 ft long; it is approximately 4,000 ft wide in the Basin A area and narrows to less than 700 ft wide in the Basin A Neck area. Median concentration of volatile aromatic organics within the plume is 35.34 ug/l. The plume generally occurs in areas of saturated alluvium. However, it is present in the unconfined Denver Formation below unsaturated alluvium in the north and northeast portions of Section 36. A comparison of MKE (unpublished data, 1986) historical assessments and Third Quarter FY87 efforts indicates that a portion of the volatile aromatic organics plume may extend southward into Sections 1 and 2. Data were not acquired for this area prior to Third Quarter FY87 sampling, and available recent data do not refute occurrence of volatile aromatic organics within this area. The source of the plume is possibly the South Plants/Basin A area.

The alluvial volatile aromatic organics plume in the Basin F pathway extends northeast from the Basin F area to the North Boundary Containment System (Figure 4.2-9). The apparent highest concentration within this plume occurs at Well 26133 (>550 ug/l), with the lowest detectable concentration occurring at Well 24049 (4.67 ug/l). The plume concentration appears to decrease to less than 50 ug/l immediately north of the line between Sections 23 and 26. Occurrences are generally between 10 and 30 ug/l within the Basin F pathway. The plume exhibits a maximum width of approximately 1,500 to 1,700 ft in Section 23, and is approximately 6,000 ft long as contoured. The plume generally occurs in areas of saturated alluvium/unconfined Denver, but may occur exclusively in unconfined portions of the Denver Formation beneath areas of unsaturated alluvium. This appears to be the case in the northern portion of Section 26.

A volatile aromatic organics plume occurs in the Northern Off-Post pathway just north of the North Boundary Containment System in Section 13, and continues northward through Section 12. This plume exhibits relatively lower total volatile aromatic organics concentrations than on-post plumes, with the highest volatile aromatic organic concentration occurring at Well 37377 (28.5 ug/l). The lowest concentration is at Well 37389 (2.49 ug/l). The highest concentration portion of the plume as contoured occurs in Section 13 and is diluted northward (Figure 4.2-9). The plume is approximately 2,500 ft wide through Section 13, decreasing to less than 1,000 ft wide in Section 12 and is over 6,000 ft long. The Northern Off-Post plume occurs in areas of saturated alluvium and is probably a residual plume that occurred in the area prior to installation of the North Boundary Containment System.

A relatively low concentration plume extends through the First Creek Off-Post pathway in the off-post area northwest through Section 14. The highest concentration of total volatile aromatic organics in this plume occurs at Well 37370 (35.8 ug/l) and lowest at Well 37381 (2.6 ug/l) with the majority of detections within the plume at concentrations less than 10 ug/l. The plume is approximately 4,000 ft long and 1,000 ft wide, and occurs in an area of unsaturated alluvium. Both the First Creek Off-Post and Northern Off-Post pathway plumes appear to be remnant occurrences isolated from on-post plumes by activation of the North Boundary Containment System.

A relatively low concentration volatile aromatic organics plume extends in the off-post area northwest of Quincy Street near the Northwest Boundary Containment System through Sections 21 and 22. The maximum volatile aromatic organics concentration occurs at Well 37335 (10.29 ug/l) and lowest at Well 37330 (2.69 ug/l), with the remainder of the wells in the plume exhibiting concentrations less than 10 ug/l. The plume is approximately 4,000 ft long and 3,000 ft wide, and occurs in an area of saturated alluvium. This occurrence is not in conjunction with any identified volatile aromatic organic sources in the immediate area but probably is related to contamination sources in the vicinity of Basins C, D and E.

Denver Aquifer

The volatile aromatic organics occur more extensively in the confined portion of the Denver Formation than any of the other organic compound groups identified at RMA. A total of 141 Denver wells were analyzed for volatile aromatic organics, with 32 wells containing detectable volatile aromatic organic concentrations.

Recent data indicate that benzene and chlorobenzene are the most commonly detected volatile aromatic organics within the Denver Formation and are detected at many of the same locations. Toluene, ethylbenzene, meta-xylene and ortho- and para-xylene are detected much less frequently than chlorobenzene or benzene, but always in conjunction with either of these two compounds. Well 27054 is an exception, containing 17 ug/l toluene, but no other volatile aromatic organics. No alluvial volatile aromatic organic detections occur in this area, and the source of this Denver detection is unknown. Point plots of all volatile aromatic organic detections within the Denver zones are presented in Appendix D. Volatile aromatic organic detections within the Denver Formation occur in Sections 1, 23, 24, 26 and 36 and off-post. Since chlorobenzene and benzene occur at all but one of these locations, detailed discussion of volatile aromatic organics distribution for the Denver Formation is included under the individual chlorobenzene and benzene discussions.

4.2.7.2 Benzene

Analyses for benzene were conducted on 472 groundwater samples collected from both alluvial and Denver wells during the Third Quarter FY87 sampling event. Benzene concentration ranged from 1.49 to 25,000 ug/l with a median concentration value of 4.26 ug/l. Benzene was detected in confined Denver Formation groundwater within zones A, 1u, 1, 2, 3, 4 and 5. The following section discusses benzene occurrence in the Unconfined Flow System (Figure 4.2-10) and Denver Formation (Figure 4.2-11), with point plot maps of Denver Formation benzene detections presented in Appendix D. Alluvial, unconfined Denver Formation and confined Denver Formation benzene detections are summarized in Table 4.2-5.

Historical Water Quality Data

Benzene is a solvent associated with pesticide manufacture and is also found in gasoline (Ebasco, 1988b, RIC#88357R01). Little data regarding volatile compound occurrence in RMA groundwater were collected prior to the 1980s. Historical occurrence maps constructed by MKE (unpublished data, 1986) indicate that over 1,000 ug/l benzene was detected in alluvial groundwater in the southern and central portions of Sections 1 and 2. Benzene was also detected in Basin A/Basin A Neck area alluvial groundwater, with Denver Formation detections throughout Sections 23, 24, and 26.

Initial Screening Program assessments confirmed the occurrence of greater than 1,000 ug/l benzene in alluvial groundwater through the Basin A area and also showed detections greater than 100 ug/l in the Basin F pathway. Initial Screening Program Denver Formation detections occurred with concentrations between 10 and 100 ug/l in Sections 23, 26 and 35 and the area around Basins C, D, E and F. A very high concentration (151,000 ug/l) but apparently isolated Denver Formation detection occurred under the South Plants area, with relatively low-level Denver Formation detections in Sections 2, 3, 6, 19, 22, 25, 27 and 32. The high value has not been confirmed in subsequent sampling.

Unconfined Flow System

A total of 331 Third Quarter FY87 groundwater samples from alluvial (296) and unconfined Denver Formation (35) wells were analyzed for benzene, with a total of 36 benzene detections in the Unconfined Flow System. Certified reporting limits for benzene ranged from 1.34 to 1.92 ug/l. Table 4.2-11 summarizes benzene detections in the alluvium and in each unconfined Denver zone. Benzene concentrations range from 1.49 to 25,000 ug/l. Benzene was detected within the Basin A - South Plants pathways, Basin F-Basin F East pathways, North Off-Post pathway, and in isolated detections in the north off-post, northwest off-post, and RMA western tier areas.

As indicated by Third Quarter FY87 data, the alluvial groundwater plume in the Basin A-South Plants pathway area extends from the northern portion of Section 1 through the Basin A area (Figure 4.2-10). Benzene concentration within the plume area ranges from 1.5 ug/l at Well 36065 to 25,000 ug/l at Well 36001. Two relatively high concentration areas centered around Wells 36001 and 36084 occur within this plume. The contoured plume width is approximately 3,000 ft, and the length approximately 4,000 ft. Benzene does not occur above the contoured certified reporting limit through the Basin A Neck area as interpreted from Third Quarter FY87 data.

Historical data indicated that the benzene plume may extend to the south-southwest through Sections 1 and 2 (Figure 4.2-10). Well 01014 is in this area and is screened in the unconfined portion of the Denver Formation. Although not sampled during Third Quarter FY87, earlier sampling indicated that benzene in Well 01014 occurs in excess of 329,000 ug/l. Third Quarter FY87 data distribution neither confirms nor denies this

Table 4.2-11 Summary of Analytical Results for Benzene for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm

Geologic Unit	No. of Samples Analyzed	No. of Detections	Range of Detection (ug/l) ¹	No. of EDLs [*]	Range of EDLs (ug/l) ¹
ALLUVIUM	296	31	1.49 - 25,000.00	4	13.4 - 134.0
DENVER					
B, Unconfined	0	0	--	0	--
B, Confined	3	0	0	0	--
VC/VCE, Unconfined	7	1	16,000.00	0	--
VC/VCE, Confined	0	0	0	0	--
A, Unconfined	3	0	--	0	--
A, Confined	28	2	1.63 - 2.00	0	--
1u, Unconfined	0	0	--	0	--
1u, Confined	13	1	1.67	0	--
1, Unconfined	8	0	--	1	26.80
1, Confined	16	1	4.82	0	--
2, Unconfined	13	4	2.15 - 19.60	0	--
2, Confined	28	7	1.78 - 73.80	0	--
3, Unconfined	4	0	--	0	--
3, Confined	20	9	3.30 - 24.60	0	--
4, Unconfined	0	0	--	0	--
4, Confined	20	5	3.65 - 10.30	0	--
5, Confined	9	2	3.05 - 4.68	0	--
6, Confined	2	0	--	0	--
7, Confined	2	0	--	0	--

¹ Micrograms per liter
^{*} Elevated detection limit

Source: ESE, 1988.

occurrence. Possible source areas for the Basin A - South Plants occurrence were the South Plants facilities, Basin A, a source area in the southwestern portion of Section 36 and a potential source along the eastern margin of Basin A.

Benzene occurs in a plume of relatively low concentration that extends along the Basin F East pathway. This plume merges with another plume extending northeast from Basin F along the Basin F pathway (Figure 4.2-1). Concentration of benzene in the Basin F pathway diminishes from 508 ug/l (Well 26133) to 4.67 ug/l (Well 24049) with an average concentration of 5 to 10 ug/l. The plume exhibits an apparent, relatively abrupt concentration decline along its boundaries. Well 26073 exhibits a benzene concentration of 2.32 ug/l which may be representative of benzene concentration in the Basin F East pathway. The Basin F - Basin F East merged plume is approximately 8,000 ft long, and exhibits a 2,000 ft maximum width. The Basin F pathway plume exhibits two relatively high concentration lobes that correspond to both the primary and secondary Basin F pathways (Figures 4.2-1 and 4.2-10). Both the Basin F East and Basin F benzene plumes occur primarily in association with saturated alluvium; however, the area where the two plumes merge near the Section 23 and 26 line exhibits unconfined groundwater flow in the Denver Formation. Basins C and F areas were possible sources of the Basin F Plume. The origin of the southern portion of the Basin F east portion of the plume may have been the chemical sewers and the Sand Creek Lateral, which occur upgradient of the detections.

The benzene plume in the North Off-Post pathway occurs in Sections 13 and 14, with a maximum concentration of 17.10 ug/l (Well 37399) and a minimum concentration of 1.72 ug/l (Well 37344). The average benzene concentration within the plume is less than 5 ug/l. The plume occurs in an area of saturated alluvium, and is mapped as approximately 8,000 ft long and 2,000 ft wide. This plume is probably a remnant, separated from on-post contamination by activity of the North Boundary Containment System.

Relatively isolated detections of benzene occur in the north and northwest off-post regions and in the Western Tier (Figure 4.2-10). Alluvial cluster Wells 04046 and 04047 show vertical benzene concentration variations, with the shallower Well 04047 containing 2.6 ug/l benzene and the deeper Well 04046 with no detectable benzene occurrences. Well 04040 also contained detectable benzene (2.1 ug/l). This occurrence is probably associated with the Western Tier pathway which is influenced by sources south and west of RMA.

Denver Aquifer

Benzene occurs in groundwater from several of the confined Denver Formation zone wells at RMA. Of the 141 confined Denver Formation wells sampled, 28 benzene detections were noted. Only four Benzene detections occurred in the 35 unconfined Denver wells sampled, and these were included with the Unconfined Flow System assessments. Table 4.2-11 lists benzene detections within a given confined zone and identifies confined and unconfined Denver Formation wells.

Based on Third Quarter FY87 data, benzene was detected above certified reporting limits in wells screened in confined Denver Formation wells in zones A, 1u, 1, 2, 3, 4 and 5. Distributions are shown in point plot maps included in Appendix D and in Figure 4.2-11.

Benzene was detected in zones A, 1u and 1. Only two wells in zone A, one well in zones 1u and one well in zone 1 contained detectable benzene concentrations (Table 4.2-11). These wells are 01015 (A), 36122 (A), 36113 (1u) and 26066 (1). Benzene concentrations were 1.63 ug/l in Well 36122, 2.00 ug/l in Well 01015, 1.67 ug/l in Well 36113, and 4.82 ug/l in Well 36113. Contamination in zone A probably is related to contamination in the overlying Unconfined Flow System. Well 36113 occurs at a cluster site with Unconfined Flow System Well 36112, which contained detectable benzene. However, benzene has not historically occurred in groundwater from Well 36113. The origin of benzene in well 26066 is unknown, as no alluvial or Denver Formation benzene occurs in the surrounding area. Relatively small benzene plumes occur near and around the North Boundary Containment System in Denver Formation zones 2, 3, and 4. These plumes are shown on Figure 4.2-11.

Benzene was detected in seven confined and four unconfined wells from Denver Formation zone 2 (Table 4.2-11). The Denver plume occurred in the northwest portion of Section 24, northeast corner of Section 23 and may extend slightly into the off-post area. Wells 24167 and 23218 comprise this plume, which is approximately 1,500 ft long and 500 ft wide as currently mapped, exhibited an average concentration of less than 10 ug/l benzene. Isolated detections of benzene occurred in confined portions of zone 2 in Wells 23180, 23181, 26129 and 37387 (Figure 4.2-11, Table 4.2-11). Groundwater from unconfined Denver Formation wells 23053, 23106, and 24063 contained detectable concentrations of benzene but were mapped and assessed with the Unconfined Flow System.

Confined Denver Formation zone 3 contained one relatively small but mappable benzene plume, as well as five isolated benzene detections. A plume exists in the northwest corner of Section 24 and continues through the northeast corner of Section 23 and into the off-post area (Figure 4.2-11). Wells 24136, 24168, 23219 and 37390 are included within the plume boundary. The plume is approximately 2,250 ft long and 1,500 ft wide as mapped, with an average benzene concentration of approximately 5 ug/l.

Zone 3 benzene occurrences were also detected in groundwater samples from unconfined Denver Formation Wells 22027, 23190, 23192, 37376 and 37379 (Figure 4.2-11). Wells 23190 and 23192 were not included within a plume boundary because these wells are across gradient from each other.

Zone 4 benzene occurrences were detected in unconfined Denver Formation Wells 23187, 24175, 37372, 37380 and 37382 (Figure 4.2-11, Table 4.2-11). The highest benzene concentration occurred at Well 37372 (10.3 ug/l) and the lowest at Well 37380 (3.65 ug/l). Groundwater from Wells 04009 and 24172, screened in zone 5, also contained relatively low level, but detectable concentrations of benzene (Table 4.2-11). Wells screened in zones 6 and 7 that were included in the Third Quarter FY87 network contained no detectable benzene.

Benzene in these Denver Formation zones does not occur in association with apparent overlying alluvial contamination. However, alluvial benzene does occur immediately upgradient of these plumes, and may have been a potential source of contamination. The origin of isolated benzene detections outside of the plume areas in Denver Formation zones is not apparent.

4.2.7.3 Chlorobenzene

Analysis for chlorobenzene was conducted on 473 groundwater samples from both alluvial and Denver wells during the Third Quarter FY87 sampling event. Chlorobenzene concentration ranged from 0.582 to 31,200 ug/l, with a median concentration value of 8.48 ug/l. Chlorobenzene was detected in confined Denver Formation zones A, 1u, 1, 2, 3, 4 and 5. The following sections discuss chlorobenzene occurrence in the alluvium (Figure 4.2-12) and the Denver Formation (Figure 4.2-13), with point plot maps of Denver Formation chlorobenzene detections presented in Appendix D. Alluvial, unconfined Denver

Formation and confined Denver Formation chlorobenzene detections are summarized in Table 4.2-5.

Historical Water Quality

Chlorobenzene is a raw chemical that was used in RMA operations and is a solvent in thionyl chloride synthesis (Ebasco, 1988b, RIC#88357R01). Information presented in the Initial Screening Program report indicates that chlorobenzene was detected during this sampling event in alluvial wells in Sections 1, 26, 35 and 36 (ESE, 1987a, RIC#87253R01). Isolated chlorobenzene detections occurred in Sections 2 and 26. Chlorobenzene occurred in Denver wells sampled during the Initial Screening Program in Sections 26 and 35, with one isolated detection in Section 1. Historical volatile aromatic organics distribution plots presented by Spaine (1984, RIC#85133R04) indicated the occurrence of chlorobenzene in Section 1 but did not differentiate between alluvial and Denver detections.

Unconfined Flow System

A total of 331 groundwater samples from alluvial (297) and unconfined Denver Formation (35) wells were analyzed for chlorobenzene with 52 detections. Chlorobenzene concentration in the alluvium ranges from 0.582 to 31,200 ug/l, with a median concentration of 6.91 ug/l. Table 4.2-12 summarizes chlorobenzene detections in alluvial and unconfined Denver Formation wells. Certified reporting limits for chlorobenzene are between 0.58 and 1.36 ug/l. Chlorobenzene was detected within the Basin A pathway, South Plants pathway and through the Basin A Neck pathway. Chlorobenzene is also detected in groundwater within the First Creek and Northern Off-Post pathways. Isolated chlorobenzene detections occur in the north and northwest off-post areas, and in on-post Sections 4, 6, 7 and 8.

Chlorobenzene was detected in the Basin A, South Plants and Basin A Neck pathways and extends from the northern portion of Section 1 through the western portion of Section 36, and through the Basin A Neck area into the southern portion of Section 26 (Figure 4.2-12). This occurrence is discussed as one plume, although it may have received contamination from more than one source area, such as the Basin A/South Plants area. The highest detectable concentration within this plume area occurs at Well 36001 (31,200 ug/l) and lowest at Well 36065 (0.98 ug/l), with a relatively high concentration at unconfined Well 36090 (55.9 ug/l). The plume is approximately 2 miles long in the

Table 4.2-12 Summary of Analytical Results for Chlorobenzene for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm

Geologic Unit	No. of Samples Analyzed	No. of Detections	Range of Detection (ug/l) ¹	No. of EDLs*	Range of EDLs (ug/l) ¹
ALLUVIUM	297	49	0.582 - 31,200.0	3	1.73-58.0
DENVER					
VC/VCE, Unconfined	7	2	55.9 - 1,170.0	0	--
VC/VCE, Confined	0	0	--	0	--
B, Unconfined	0	0	--	0	--
B, Confined	3	0	--	0	--
A, Unconfined	3	0	--	0	--
A, Confined	28	1	2.33	0	--
1u, Unconfined	0	0	--	0	--
1u, Confined	13	1	19.5	0	--
1, Unconfined	8	1	1.74	1	11.6
1, Confined	16	2	3.81 - 8.62	0	--
2, Unconfined	13	0	--	0	--
2, Confined	28	6	0.79 - 74.7	0	--
3, Unconfined	4	0	--	0	--
3, Confined	20	6	9.50 - 33.0	0	--
4, Unconfined	0	0	--	0	--
4, Confined	20	6	3.60 - 42.4	0	--
5, Confined	9	2	7.74 - 17.4	0	--
6, Confined	2	0	--	0	--
7, Confined	2	0	--	0	--

¹ Micrograms per liter
* Elevated detection limit

Source: ESE, 1988.

downgradient direction and exhibits a maximum width of 4,000 ft. The plume occurs principally in saturated alluvium; however, the northern portions of the plume occur in the Denver Formation where the alluvium is unsaturated.

Isolated detections of chlorobenzene occur in the eastern portion of Section 26 to the northern section boundary (Figure 4.2-12). The highest detection occurred at Well 25133 (28.5 ug/l) and the lowest at Well 26127 (1.09 ug/l). Isolated elevated certified reporting limits occur in the Basin F pathway northeast of this plume in Wells 23004 (<58.0 ug/l) and 23049 (<11.6 ug/l). No confirmed detections occurred in this area during the Third Quarter FY87 sampling period.

Isolated detections of chlorobenzene also occur in the Quincy Street pathway in the off-post area northwest of the Northwest Boundary Containment System (Figure 4.2-12). The highest detection in this plume occurs at Well 37335 (8.55 ug/l) and the lowest at Well 37330 (2.69 ug/l). The plume exhibits a roughly oval pattern that extends over a 3,500 by 3,000 ft area and occurs in an area of saturated alluvium. An isolated detection occurs approximately one mile downgradient at Well 37361 (7.76 ug/l). The origin of this occurrence is not apparent.

Chlorobenzene occurs in the North Off-Post pathway and extends to the north through off-post Sections 12 and 13 (Figure 4.2-12). The highest concentration of chlorobenzene within this plume occurs at Well 37377 (22.7 ug/l) and lowest at Well 37341 (2.42 ug/l). The plume is greater than 9,000 ft long and 2,000 ft wide, and occurs in saturated alluvium/unconfined Denver. This plume may be remnant contamination isolated by activity of the North Boundary Containment System.

The First Creek Off-Post pathway contains a chlorobenzene plume that extends southeast to northwest through Section 14. The highest detectable concentration of chlorobenzene occurs at Well 37370 (27.3 ug/l) and lowest at Well 37381 (2.68 ug/l). As mapped, the chlorobenzene plume within this pathway is approximately 4,000 ft long and over 1,000 ft wide, and occurs in an area of saturated alluvium/unconfined Denver. Both the First Creek Off-Post and Northern Off-Post occurrences are probably remnants separated from on-post plumes by activity of the North Boundary Containment System.

Chlorobenzene occurs as isolated detections in the on-post and off-post areas and the Western Tier (Figure 4.2-12). Isolated detections in the on-post area occur in Section 4, 6, 7, 8 and 33. Alluvial cluster site Wells 04042 and 04043 in Section 4 suggest that there is a vertical concentration gradient in this area. The shallower alluvial Well 04042 contains chlorobenzene (1.8 ug/l), and the deeper Well 04043 does not. Isolated detections of chlorobenzene occur in several off-post locations (Figure 4.2-12), with the highest concentration at Well 37363 (9.42 ug/l).

Denver Aquifer

Chlorobenzene occurs in groundwater collected from 24 of the 141 confined Denver, and 3 of the 35 unconfined Denver wells included in the Third Quarter FY87 sampling network. Table 4.2-12 lists chlorobenzene detections within the confined and unconfined portions of a given zone, and also identifies confined and unconfined Denver wells.

Based on Third Quarter FY87 data, chlorobenzene was detected above certified reporting limits in samples collected from wells screened in confined Denver Formation, in zones A, 1u, 1, 2, 3, 4 and 5. Distributions are shown on point plot maps included in Appendix D and in Figure 4.2-13.

Relatively few occurrences of chlorobenzene occur within Denver zones VC/VCE, A, 1u or 1 (Table 4.2-12). Wells 36056 and 36090 are screened within the volcanoclastic interval and exhibit relatively high chlorobenzene concentrations of 1,170 ug/l and 55.90 ug/l, respectively; however, these wells were included with the unconfined aquifer.

One confined Denver Formation chlorobenzene occurrence of 2.33 ug/l was detected in the A zone from Well 35066. The Unconfined Flow System above this well contains chlorobenzene (Well 35065, >5.7 ug/l), and may be associated with chlorobenzene occurrence at Well 35066. One well completed in zone 1u contained chlorobenzene at detectable concentrations (19.5 ug/l). The well is located in the Basin A Neck beneath an area of the Unconfined Flow System contaminated by chlorobenzene. Three wells in Denver zone 1 contained detectable chlorobenzene and one sample exhibited an elevated detection limit, perhaps indicative of chlorobenzene occurrence (Table 4.2-12). However, two of these wells are screened in the unconfined portions of the Denver (26041 and 26071). Well 26066, which exhibits a chlorobenzene concentration of 8.62 ug/l, occurs approximately 1,500 ft downgradient from Well 26086, that contained 3.81 ug/l

chlorobenzene. The unconfined system contains low levels of chlorobenzene in the area and may have contributed to Denver contamination. However, alluvial Well 26085 shows no chlorobenzene contamination, indicating that contamination in Well 26086 was probably not derived from directly overlying Unconfined Flow System water.

Denver Formation zones 2, 3, and 4 contain chlorobenzene within specific, localized areas in each zone. No Denver Formation wells that are screened in the unconfined aquifer in these zones exhibit chlorobenzene contamination.

Figure 4.2-13 shows the location of zones 2, 3, and 4 wells, and also shows the location of relatively small but definable plumes within confined portions of the Denver Formation. The zone 2 chlorobenzene plume occurred in the northwest corner of Section 24, downgradient of the North Boundary Containment System and incorporated Wells 24167, 24171, 24191 and 23218. The mapped width of the plume is approximately 2,000 ft, and the length downgradient is approximately 1,500 ft. Isolated chlorobenzene detections occurred in Wells 26129 and 37387 (Table 4.2-12, Figure 4.2-13).

Zone 3 also contained a small chlorobenzene plume that occurs downgradient of the North Boundary Containment System. The plume was centered in the northwest corner of Section 24, but extends slightly off-post (Figure 4.2-13). Wells 23219, 24168 and 37390 are included in the plume and contain chlorobenzene concentrations of 16.90, 14.40, and 23.70 ug/l, respectively. The mapped width of the plume is 1,250 ft, and the maximum mapped length is approximately 1,875 ft. Wells 37379 and 37376 also contained chlorobenzene at concentrations of 17.8 and 33.0 ug/l, respectively.

A zone 4 chlorobenzene plume extends from the northwest corner of Section 23 to southern portions of off-post Section 14. Wells 23201, 37372 and 37388 are included in the plume and contain 8.39 ug/l, 42.40 ug/l, and 32.80 ug/l chlorobenzene, respectively. The mapped width of the plume is approximately 1,500 ft and the length is approximately 2,300 ft. Well 37380 outside of the plume area contained 15.4 ug/l chlorobenzene, and Well 24175 contained 16.70 ug/l chlorobenzene.

Two wells in confined Denver Formation zone 5 contained detectable concentrations of chlorobenzene. Well 24172 contains 17.40 ug/l, while Well 37322 contains 7.40 ug/l

chlorobenzene (Appendix D). Wells sampled from zones 6 and 7 contained no detectable chlorobenzene.

As with benzene, chlorobenzene occurrence in these plumes was probably derived from an upgradient alluvial plume, and may have been influenced to a minor degree by hydrologic conditions created at the boundary system.

4.2.8 Volatile Halogenated Organics

Analyses for volatile halogenated organics were conducted on 472 well samples, of which 297 were collected from alluvial wells, 141 were collected from Denver Formation wells, and 35 were collected from wells screened in the unconfined portion of the Denver Formation. The volatile halogenated organics include chloroform, methylene chloride, carbon tetrachloride, trichloroethylene, tetrachloroethylene, 1,1-dichloroethylene, trans-1,2-dichloroethylene, 1,1-dichloroethane, 1,2-dichloroethane, 1,1,1-trichloroethane, and 1,1,2-trichloroethane. Composite concentrations were calculated by summing the volatile halogenated organic concentrations at each well, with concentrations below the certified reporting limits equal to zero. Composite concentrations ranged from 0.54 ug/l to 39,800 ug/l.

A summed volatile halogenated organic compound map was prepared for the Unconfined Flow System to illustrate the occurrence of contaminants in this compound group in RMA alluvial groundwater, and is presented in Figure 4.2-14. The highest certified reporting limit of 5.0 ug/l is the lowest contour interval in this figure. The following discussion will focus on the combined contaminant distribution followed by a discussion of the major individual components. For the volatile halogenated organics, the major compounds which will be discussed in detail are chloroform, trichloroethylene and tetrachloroethylene. These three compounds were selected for discussion because they are the most frequently detected volatile halogenated organics at RMA and are representative of the combined volatile halogenated organic distribution. Denver Formation occurrences of chloroform, trichloroethylene and tetrachloroethylene will also be discussed. Alluvial, unconfined Denver Formation and confined Denver Formation detections of individual volatile halogenated organics are presented in Table 4.2-5.

4.2.8.1 Total Volatile Halogenated Organics

Total volatile halogenated organic occurrences in terms of historical and current distribution is discussed in this section. Current occurrence of total volatile halogenated organics is also presented for both the Unconfined Flow System and Denver Formation aquifers. Unconfined Flow System plumes are shown in Figure 4.2-14, and Denver Formation point plot maps are presented in Appendix D.

Historical Water-Quality Data

Water-quality data acquired prior to the Initial Screening Program for the volatile halogenated organic compounds are very limited, as volatile halogenated organic sampling was not performed regularly until the 1980s. MKE distribution maps (unpublished data, 1986) indicate historical chloroform and carbon tetrachloride occurrence in and around the South Plants area in Section 1 that extends throughout Sections 2, 36, and into the south-eastern part of Section 35.

The historical alluvial concentrations of chloroform on the MKE map (unpublished data, 1986) ranged from 1 ug/l to over 500 ug/l with one containing 953 ug/l chloroform located just north of the South Plants area in Section 36. The highest chloroform concentrations were located in the South Plants area of Section 1. Carbon tetrachloride was also shown to exist in the South Plants area, with concentrations ranging from 10 to over 1,000 ug/l. The carbon tetrachloride distribution, however, was strictly confined to the immediate South Plants area of Section 1, while low level chloroform contamination was shown in the South Plants and Basin A areas of Sections 1, 2 and 36 and extending into south-eastern Section 35.

Denver Formation contamination was also shown to exist on the MKE maps for both chloroform and carbon tetrachloride. Chloroform concentrations ranged from 1 to over 1,000 ug/l, with the highest concentrations generally in the South Plants area, the burn pits in Section 36 adjacent to Basin A and the Basin A Neck area in the extreme northwest of Section 36. Low level concentrations were plotted throughout Sections 1, 2, 36 and the eastern half of Section 35. Denver Formation carbon tetrachloride contamination appeared in the South Plants area in concentrations greater than 1,000 ug/l, with an isolated well in Section 36 showing 1,635 ug/l.

For Initial Screening Program data collected during September 1985 to March 1986, volatile halogenated organics appeared in several locations including: the Basin A - South Plants area; the Basin F area in Sections 1, 2, 23, 24, 26 and 35; the North Boundary Containment System area in Sections 22 and 27; the Central Basins South pathway in Sections 34 and 35; and the Western Tier - Rail Classification Yard area of Sections 3, 4, 9 and 33 extending to the western off-post area. The highest alluvial concentrations of total volatile halogenated organics appeared in the South Plants - Basin A area of northern Section 1 and southern Section 36 with over 100,000 ug/l, and also occurred in excess of 100,000 ug/l northeast of Basin F in Section 23. Lower concentrations appear in the other areas (Rail Classification Yard concentration approximately 100 ug/l). During the Initial Screening Program, volatile halogenated organics in the Denver Formation occurred mainly as isolated detections. Isolated detections of less than 4 ug/l occurred in Sections 4, 25, 26, 27 and 35. The EPA collected groundwater samples prior to 3rd Quarter FY87 in the area west of RMA. These data are included in plume maps presented in this section.

Unconfined Flow System

During the Third Quarter FY87, analysis for volatile halogenated organics were conducted on 297 alluvial and 35 unconfined wells, with 181 of these wells containing detectable amounts of volatile halogenated organics. Detectable concentrations ranged from 0.54 ug/l to 39,800 ug/l. Combined volatile halogenated organic plumes occur within a number of contaminant pathways or contaminant pathway groups at RMA (Figures 4.2-1 and 4.2-14). Plumes presented in earlier sections occur in distinct pathways. In the case of the volatile halogenated organics, however, occurrence is more widespread and plumes within individual pathways appear to merge, forming larger composite plumes. Because of this, the following total volatile halogenated organic discussion will be presented in terms of pathway groupings through which volatile halogenated organic plumes extend. These include:

- o Basin A - South Plants - Basin A Neck;
- o Central pathway, which includes the Central South, Central North, and Quincy Street pathways;
- o North Off-Post - First Creek;
- o Basin F - Basin F East; and
- o Western Tier - Rail Classification Yard.

Isolated detections occur in the north and northwestern off-post areas and on-post Sections 1, 2, 3, 8, 23, 24, 26, 28 and 36. In addition, data from noncontemporaneous EPA wells are included on the map together with data collected for the RI.

The volatile halogenated organics plume in the Basin A - South Plants - Basin A Neck pathways area extends from the Basin A and the South Plants areas in Sections 1 and 36 southeast into Section 1. The plume also extends to the southwest through the four corners area of Sections 1, 2, 35 and 36 and westward through Section 2. The plume area also occurs from the South Plants area through Basin A and into the Basin A neck pathway. This section of the plume continues along the Basin A neck pathway into the Central Pathways area (Figure 4.2-1).

Concentrations of volatile halogenated organics in this combined pathway area range from 9.64 ug/l in Well 01008 to 16,900 ug/l in Well 36076. The highest concentration area is in the southwest corner of Section 36. A second high concentration area occurs in the east-central portion of Section 36 with concentrations up to 487 ug/l in unconfined Well 36090. The plume is 5,000 ft wide and extends over 15,000 ft from its southern tip in Section 2 to the Basin A Neck pathway (Figures 4.2-1 and 4.2-14). The plume occurs for the most part in areas of saturated alluvium/unconfined Denver, except in portions of Sections 1 and 2 and along the northern margin of Section 36, where volatile halogenated organics occur exclusively in unconfined portions of the Denver Formation. Potential sources of volatile halogenated organics included the South Plants area, Basin A and a source area in the northwest portion of Section 36.

Plumes in the Central pathway area occur in three smaller pathways that include the extreme northern portion of Basin A Neck pathway, the Central North pathway and the Central South pathway. Plumes from these pathways merge about halfway between B and C streets in Sections 34 and 27 (Figure 4.2-14) and flow to and around the Northwest Boundary Containment System in Section 22. The flow around the boundary system continues off-post via the Quincy Street Pathway about 1,000 ft. The concentrations within this plume range from 5.26 ug/l in Well 35058 to 53.3 ug/l in Well 27073. In the vicinity of the Northwest Boundary Containment System, the concentrations range from 7 to 36 ug/l, with most concentrations between 10 and 30 ug/l. Plumes in these pathways are generally confined to areas of saturated alluvium although flow may occur also in

unconfined portions of the Denver Formation. The Central North and Central South pathways (Figure 2.4-1) are independent of any other plume, while the Basin A Neck pathway continues from the Basin A area. Plumes within the Central Pathway are over 8,000 ft long, but are generally less than 2,000 ft wide as mapped using Third Quarter FY87 data. Potential sources of volatile halogenated organics in these pathways included RMA basins along the Basin A Neck pathway that may also be a continuation of contamination from the Basin A - South Plants area. Contaminant sources for the central pathways plume are difficult to assess. The Sand Creek Lateral may have been a possible source.

The plume in the Northern Off-Post - First Creek pathways area extends from the North Boundary Containment System and includes the First Creek pathway and the Northern Off-Post pathway (Figures 4.2-1 and 4.2-14). Concentrations in this plume range from 5.72 to 1,515 ug/l. This plume extends approximately 10,000 ft north along the Northern Off-Post pathway from the North Boundary Containment System into Section 12 where it curves to the northwest, around an unsaturated area. This plume also has a component that occurs along the First Creek pathway and extends about 2,500 ft to the northwest. Concentrations along the First Creek pathway are relatively low (<50 ug/l). The Northern Off-Post pathway portion of the plume is about 1,500 ft wide and occurs in saturated alluvium/unconfined Denver. The First Creek pathway is no more than 1,000 ft wide and also occurs in an area of saturated alluvium/unconfined Denver. Plumes along these pathways may have once been extensions of contamination from the Basin F pathway but were separated by the North Boundary Containment System and now appear to be remnant contamination.

The plume in the Basin F - Basin F East pathways area occurs in Sections 26, 23, and 24. The plume extends from near Basin C and the chemical sewer (Figure 1.3-1) and extends north in saturated alluvium to the northern edge of Basin F. The plume then extends under unsaturated alluvium into unconfined portions of the Denver Formation near Basin F and extends to the northeast through Sections 23 and 24 toward upgradient of the North Boundary Containment System. The concentrations range from 6.24 to 39,800 ug/l in this plume area.

Concentrations begin to decrease about 1,500 ft southwest of the North Boundary Containment System. Less than 1,000 ug/l of volatile halogenated organics occur in the

northwest part of Section 24, and does not extend beyond the North Boundary Containment System, indicating apparent relatively effective volatile halogenated organics remediation by the North Boundary Containment System. The plume exhibits a maximum width of approximately 2,000 ft and is over 6,000 ft long through the Basin F East-Basin F pathways. Basin F appears to have been a potential source of the Basin F plume. Although no definite source of the Basin F east occurrence is apparent, chemical sewers and the Sand Creek Lateral occur in upgradient areas of this pathway.

The volatile halogenated organics plume in the Western Tier - Rail Classification Yard Pathways occurs in Sections 9, 3, 4, and 33. These two pathways merge together in the northern portion of Section 4 and continue northwest through Section 33. Concentrations of contaminants through this plume area range from 5.16 to 157.47 ug/l. The highest concentrations occur in the Rail Classification Yard area in eastern Section 4 and through the middle of Sections 9, 4 and 33. Maximum plume width is over 4,000 ft and maximum length is over 15,000 ft along the Western Tier pathway and over 4,000 ft along the Railyard pathway. EPA data indicate the occurrence of volatile halogenated organics in the off-post area immediately west of the Western Tier pathway (Figure 4.2-14). Concentrations in these wells range from 5 to 194 ug/l. The highest concentration in this area occurs just south of 72nd Avenue, extends through Sections 5, 6, 7, 8, 31 and 32 in the off-post area west of RMA. Volatile halogenated organics occurrence along the western margin of RMA indicates the presence of sources both off-post and on RMA in this area.

Low-level isolated occurrences of volatile halogenated organics were detected in north and northwest off-post areas and in on-post areas as well. These occurrences range in concentration from above 5 ppb to 51 ug/l and demonstrate fairly low concentrations.

Denver Aquifer

Unlike the volatile aromatic organics group, the majority of the volatile halogenated organics detections identified within the Denver Formation were in wells screened in the unconfined aquifer, with detections that occurred in the confined aquifer considered as isolated occurrences. Chloroform, trichloroethylene and tetrachloroethylene are the most commonly detected compounds in the Denver Formation (Appendix D). The other compounds in the group, such as carbon tetrachloride and 1,1-dichloroethane, were detected in five samples from the Denver Formation, all of which were in conjunction

with chloroform, trichloroethylene or tetrachloroethylene. For all compounds, point plots are provided in Appendix D to show the Denver Formation occurrences. Major detections of volatile halogenated organics in the Denver Formation occur in Sections 1, 2, 23, 24, 35, 36 and off-post. The distribution of chloroform, trichloroethylene and tetrachloroethylene in the Denver Formation is presented under individual compound discussions.

4.2.8.2 Chloroform

Chloroform analyses were conducted on a total of 473 groundwater samples from wells screened in both alluvium and Denver Formation during the Third Quarter FY87 sampling program. A total of 147 detections were found, with concentrations ranging from 0.54 to 38,800 ug/l and a median concentration of 16.5 ug/l. Chloroform was detected in confined portions of Denver Formation zones A, 1u, 1, 2, 5 and 6. The following discusses historical chloroform occurrence in groundwater, as well as Unconfined Flow System (Figure 4.2-15) and Denver Formation occurrences (Appendix D). The lowest contour interval is 1.9 ug/l, with certified reporting limits between 0.50 ug/l and 1.9 ug/l. Alluvial, unconfined Denver Formation and confined Denver Formation chloroform detections are summarized on Table 4.2-5.

Historical Water Quality Data

Chloroform is a solvent that was associated with Azodrin (an insecticide) and Bidrin manufacture (Ebasco, 1988b, RIC#88357R01). Most of the chloroform analyses that have been done on RMA groundwater have been conducted only recently. MKE (unpublished data, 1986) constructed historical occurrence maps that showed chloroform contamination through the South Plants - Basin A area in concentrations ranging from 1 to 1,000 ug/l, with the highest concentrations located in the immediate vicinity of the South Plants. Both alluvial and Denver Formation contamination were identified here. Initial Screening Program data showed widespread occurrence of chloroform contamination in the alluvium in the South Plants area through Basin A and the Basin A Neck and from Basin F to the North Boundary Containment System. Relatively low-level, isolated detections of chloroform occurred in Denver Formation wells in Sections 4, 25, 26, 27 and 35.

Unconfined Flow System

A total of 332 groundwater samples from alluvial (297) and unconfined Denver (35) wells were analyzed for chloroform, of which 109 alluvial and 19 unconfined Denver wells contained detectable concentrations of chloroform. Concentrations range from 0.54 to 38,800 ug/l. Table 4.2-13 summarizes alluvial, unconfined Denver Formation, and confined Denver Formation chloroform occurrence. Major occurrences of chloroform were detected in the Basin A - South Plants - Basin A Neck pathways, Basin F - Basin F East pathways, the North Off-Post pathway and the Central pathway. Smaller plumes and isolated detections occur in the Rail Classification Yard area of Sections 3 and 4; Sections 2, 3, 24, and 28; and in the off-post to the north and northwest of RMA (Figure 4.2-15).

The chloroform plume that occurs in the Basin A - South Plants - Basin A Neck pathways extends from Sections 36 and 1 through Sections 1 and 2, up through the northeastern portion of Section 36 and into the Basin A Neck. Concentrations in this plume range from 2.61 ug/l in Well 01017 to 11,100 ug/l in Well 36076. Highest concentrations occur in the extreme southwest Basin A area of Section 36 and decrease outward from this area (Figure 4.2-15). The plume occurs in unconfined portions of the Denver Formation below unsaturated alluvium in the northeast margin of Basin A and the eastern portion of Section 35. Chloroform also occurs in the unconfined portion of the Denver Formation under a large area of unsaturated alluvium in the northeast corner of Section 2 and the four corners area of Sections 1, 2, 35, and 36. This area includes unconfined Wells 35013 (12.2 ug/l) and 01007 (27.0 ug/l). The plume extends through the Basin A Neck area, but concentrations decrease below the highest certified reporting limit in the southern portion of Section 26. Possible sources of chloroform were the general South Plants area and/or a source in southern portions of Section 36.

Chloroform also occurs in a plume that extends north along the Basin F East pathway into the Basin F pathway and merges with a plume apparently from Basin F and extending northeast to the North Boundary Containment System. The concentrations of chloroform in this merged plume range from 38,800 ug/l in Well 26013 downgradient of Basin F to 2.45 ug/l in Well 24186 near the North Boundary Containment System. A high concentration area occurs near Basin F, and concentrations decrease to less than the certified reporting limit at the North Boundary Containment System. Concentrations in the Basin F East pathway are relatively low. A high chloroform concentration occurs in a

Table 4.2-13 Summary of Analytical Results for Chloroform for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm

Geologic Unit	No. of Samples Analyzed	No. of Detections	Range of Detection (ug/l) ¹	No. of Detections Above the Upper CRLs ²	Range of Detections Exceeding Upper CRLs ² (ug/l) ¹
ALLUVIUM	295	109	0.54 - 38,800	0	--
DENVER					
B, Unconfined	0	0	--	0	--
B, Confined	3	0	--	0	--
VC/VCE, Unconfined	6	6	3.51 - 1,920	0	--
VC/VCE, Confined	0	0	--	0	--
A, Unconfined	3	2	12.2 - 25.4	0	--
A, Confined	29	7	1.91 - >194	0	--
1u, Unconfined	0	0	--	0	--
1u, Confined	13	1	1.71	0	--
1, Unconfined	8	1	1.99	1	28.0
1, Confined	16	4	5.18 - 26.5	0	--
2, Unconfined	13	10	2.11 - 16,500	0	--
2, Confined	28	5	2.03 - 29.5	0	--
3, Unconfined	4	0	--	0	--
3, Confined	20	0	--	0	--
4, Unconfined	0	0	--	0	--
4, Confined	20	0	--	1	14
5, Confined	9	1	6.87	0	--
6, Confined	2	1	3.10	0	--
7, Confined	2	0	--	0	--

¹ Micrograms per liter

² Certified Reporting Limits

Source: ESE, 1988.

limited area in the northwest portion of Section 24 and extends 300 ft south of the North Boundary Containment System. The merged plume is approximately 10,000 ft long from the east central portion of Section 26 to the North Boundary Containment System and is about 2,000 ft wide at its widest point. This plume occurs dominantly in areas of saturated alluvium, but occurs exclusively in unconfined portions of the Denver in the northeast portion of Section 26. The Basin F East source was possibly the chemical sewer and the Sand Creek lateral that occur east of Basin C.

The plume in the Northern Off-Post pathway extends from the North Boundary Containment System to the off-post area east of Peoria Street and continues north through Section 13. Concentrations in this pathway range from 1,370 ug/l in Well 37344 to 2.38 ug/l in Well 24162. Concentrations are lowest at the boundary system, gradually increasing to a high at Well 37392 (115 ug/l). The plume is over 7,000 ft long in this pathway and is 2,500 ft wide at its widest point. The plume occurs in an area of unsaturated alluvium, and may be a remnant plume detached from the Basin F plume by the North Boundary Containment System, although very minor amounts of chloroform may enter the area through North Boundary Containment System underflow.

Chloroform plumes in the Central pathways include the extreme northwestern extent of the Basin A Neck, localized occurrences in southeast Section 27 and in Section 34 in the Central pathway area (Figures 4.2-1 and 4.2-15). These plumes merged near the Northwest Boundary Containment System and extend slightly northwest of RMA. Most of the wells in these plumes had detections between 10 and 30 ug/l, with the highest concentration at Well 27073 (53.3 ug/l) and lowest at Well 27040 (2.94 ug/l). Plumes occur dominantly in areas of saturated alluvium, whereas plume margins may be in unconfined Denver under areas of unsaturated alluvium. A possible source of these plumes may be the Sand Creek Lateral.

Isolated detections of chloroform occur in the north and northwest off-post areas, southern Section 24, central Section 26 and southeastern Section 28. Unconfined Denver Well 36069 (136 ug/l) occurs east of the Basin A plume and is separated from Basin A by a large area of unsaturated alluvium. Small, yet mappable plumes occur in the Rail Classification Yard at Wells 03523 (8.16 ug/l) and 04036 (1.98 ug/l). A second small plume occurs in the extreme western portion of Section 2 into Section 3 (Figure 4.2-15) and includes Wells 02014 (51.3 ug/l) and 03005 (2.85 ug/l).

Denver Aquifer

One hundred forty-one confined Denver Formation wells were sampled in the Third Quarter FY87, 17 of which had chloroform detections. The sporadic distribution of these occurrences precludes contouring a continuous plume with any level of confidence.

Table 4.2-13 includes a list of Denver Formation chloroform detections by zone and by aquifer system.

Based on Third Quarter FY87 analytical results, chloroform concentrations above the certified reporting limits were detected in samples collected from confined Denver Formation wells in zones A, 1u, 1, 2, 5 and 6. Well locations and concentration of chloroform are shown in point plots included in Appendix D.

Of the six wells that contained detectable concentrations of chloroform in zone VC/VCE, all are screened in the unconfined portion of the Denver Formation. The majority of confined Denver detections were in zones A and 1, which contained seven and four detections, respectively (Table 4.2-13). The zone A confined Denver Formation detections were found in the eastern part of Section 2, the northern part of Section 35, eastern Section 1 and in Section 36. Zone A wells in Section 2 form a north-south trend and may exhibit across-gradient continuity, although data distribution in this area does not allow for positive lateral correlation. This zone A occurrence was below an Unconfined Flow System chloroform plume which may have been associated with this Denver Formation contamination. Zone 1 chloroform detections occurred in Wells 24089 (26.5 ug/l), 26058 (8.79 ug/l), and 26075 (5.18 ug/l). Alluvial chloroform contamination occurs upgradient or above all of the sites and may have influenced Denver Formation chloroform occurrences. Zone 1u contained one confined Denver detection in Well 02031 (1.71 ug/l). Well 02030 is the shallower alluvial well that is in a cluster with Well 02031 and has contained chloroform historically in excess of 100 ug/l (ESE, 1987a).

Of the 41 wells sampled from Denver Zone 2, there were 15 detections of chloroform. Ten of these were included in the unconfined portion of the Denver, all of which were located near the North Boundary Containment System in Sections 23 and 24 and in the northern off-post area. Of the five wells that were sampled in the confined portion of the Denver (Table 4.2-13), all detections were considered isolated because the distance

between wells was too great to allow for lateral correlation of detections (Appendix D). The highest confined Denver Formation zone 2 chloroform concentration occurred at Well 26061 (29.5 ug/l) and lowest at Well 23177 (2.03 ug/l). Of these five wells, 26061 and 01048 occur in areas of chloroform occurrence in the Unconfined Flow System that may have been influencing confined Denver Formation chloroform occurrence. However, Wells 37387, 23218, and 23177 do not occur in areas of alluvial chloroform contamination. These wells should be resampled to confirm chloroform contamination.

Chloroform was detected in two samples from Denver zones 3 through 7. They occurred in zone 5 at Well 24172 (6.87 ug/l), and zone 6 at Well 37319 (3.1 ug/l). These wells should be resampled to confirm chloroform contamination.

4.2.8.3 Trichloroethylene

Analyses for trichloroethylene were conducted on a total of 473 groundwater samples collected from wells screened in both the alluvium and Denver Formation during the Third Quarter FY87 sampling program. There were a total of 111 detections, with concentrations ranging from 0.71 to 2,840 ug/l and a median concentration of 4.65 ug/l. Wells screened in confined portions of Denver Formation zones A, 1u, 1, 2, 3 and 4 exhibited detectable trichloroethylene. The following discusses historical trichloroethylene occurrence, as well as distribution in the alluvial/unconfined (Figure 4.2-16) and Denver Formation (Appendix D). Alluvial, unconfined Denver Formation, and confined Denver Formation trichloroethylene detections are summarized on Table 4.2-5.

Historical Water-Quality Data

Trichloroethylene was used at RMA as a general solvent in many operations and in treatments for reimpregnating dry clean laundry (Ebasco, 1988b, RIC#88357R01). Trichloroethylene has been a compound of concern at RMA in recent years, particularly in the western tier. Initial Screening Program distribution plots show trichloroethylene in the Basin A - South Plants areas, the Basin F pathway area, the Rail Classification Yard and near the Northwest Boundary Containment System. Concentrations are greatest in the southern portion of Section 36 (over 1,000 ug/l) and the Rail Classification Yard area of Section 36 (over 100 ug/l). Isolated detections occur in Sections 2 and 9 and no occurrence was historically recognized due to limited analysis in the southern portion of

the Western Tier (Sections 4 and 9). Isolated Denver detections occurred in Sections 2, 26, 27 and 35.

Unconfined Flow System

Trichloroethylene was analyzed from 331 alluvial and unconfined Denver Formation groundwater samples that included 297 alluvial and 35 unconfined Denver Formation wells. Of these wells, 89 alluvial and 11 unconfined Denver trichloroethylene occurrences were detected. Concentrations ranged from 0.54 to 2,840 ug/l. The certified reporting limits for trichloroethylene were from 1.10 ug/l to 1.31 ug/l. Table 4.2-14 summarizes trichloroethylene occurrence in alluvial and unconfined Denver Formation wells. Major occurrences of trichloroethylene were in the Basin A - South Plants - Basin A Neck pathway, the Basin F pathway, the Northern Off-Post pathway, the Western Tier - Rail Classification Yard pathway, and in the western off-post area (Figures 4.2-1 and 4.2-16). Smaller plumes occurred in the First Creek pathway and the Quincy Street pathway, and isolated detections occurred in Sections 27 and 34.

The trichloroethylene plume in the Basin A - South Plants - Basin A Neck pathways extends from the Basin A and South Plants areas to the southeast in Section 1, to the southwest in Section 2 and to the northeast under unsaturated alluvium in Section 36 (Figure 4.2-16). This plume extends into the Basin A Neck area and continues through the Basin A Neck pathway to the Northwest Boundary Containment System. Concentrations in this plume range from 1.43 ug/l in Well 27078 to 2,840 ug/l in Well 36001.

Highest concentrations occur in the extreme southwest Basin A area, with lower concentrations in the central part of Section 36. Concentrations within the Basin A Neck area are relatively low, but trichloroethylene occurrence is apparently continuous through the narrow saturated alluvium to the Northwest Boundary Containment System. The plume occurs mainly in saturated alluvium/unconfined Denver Formation except along the northeastern margin of Basin A and in the northeast corner of Section 2 (Figure 4.2-16) where it occurs in the unconfined Denver Formation. Possible sources were the South Plants area, Basin A southern portions of Section 36 and the disposal pits in the north central portion of Section 36.

Table 4.2-14 Summary of Analytical Results for Trichloroethylene for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm

Geologic Unit	No. of Samples Analyzed	No. of Detections	Range of Detection (ug/l) ¹	No. of EDLs*	Range of EDLs (ug/l) ¹
ALLUVIUM	295	88	0.71 - 2,840	4	2.2 - 110
DENVER					
B, Unconfined	0	0	--	0	--
B, Confined	3	0	--	0	--
VC, Unconfined	7	5	1.2 - 175	0	--
VC, Confined	0	0	--	0	--
A, Unconfined	2	1	9.83	0	--
A, Confined	28	1	5.42	0	--
Iu, Unconfined	0	0	--	0	--
Iu, Confined	13	1	2.55	0	--
I, Unconfined	8	0	--	1	22
I, Confined	16	1	3.98	0	--
2, Unconfined	13	5	1.59 - 12.1	1	5.5
2, Confined	28	2	4.43 - 8.68	0	--
3, Unconfined	4	0	--	0	--
3, Confined	20	3	1.33 - 1.38	0	--
4, Unconfined	0	0	--	0	--
4, Confined	20	3	1.24 - 2.83	0	--
5, Confined	9	0	--	0	--
6, Confined	2	0	--	0	--
7, Confined	2	0	--	0	--

¹ Micrograms per liter
* Elevated detection limits

Source: ESE, 1988.

Another trichloroethylene plume begins in the southeastern portion of Section 26 and extends through the Basin F East pathway into the Basin F pathway. The Basin F east occurrence then merges with a Basin F plume and continues downgradient of Basin F to the North Boundary Containment System. Detections of trichloroethylene in this plume range from 1.33 ug/l in Well 23007 to 68.7 ug/l in Well 26133. The highest concentrations occur downgradient of Basin F in the Basin F pathway, although trichloroethylene occurs in relatively low concentrations immediately downgradient of the North Boundary Containment System. This occurrence may be attributed to flow under the North Boundary Containment System through weathered portions of the Denver Formation (ESE, 1988e, RIC#88344R02). The plume is over 9,000 ft long, and varies in width from 750 to 2,500 ft. This plume mainly exists in areas of saturated alluvium, but occurs in unconfined portions of the Denver beneath unsaturated alluvium in the northeastern portion of Section 26. The origin of the Basin F East plume is undetermined but may be related to the chemical sewers and the Sand Creek Lateral that occur east of Basin C.

Trichloroethylene occurrence within the Northern Off-Post pathway extends northward from the North Boundary Containment System into off-post Sections 12 and 13 (Figure 4.2-16). Concentrations within this area are low, ranging from 1.59 ug/l in unconfined Well 23204 (which marks the northern extent of the plume) to 7.06 ug/l in Well 37344. The plume occurs east of an area of unsaturated alluvium located in Sections 13 and 14 off-post. The plume is approximately 7,000 ft long, and is about 1,500 ft wide at its widest point. Well 23024, located just north of the North Boundary Containment System, is the only unconfined well in the plume and may be the result of very minor flow in the Denver Formation below the North Boundary Containment System. However, northern portions of the plume appear to be remnant occurrences separated from on-post plumes by operation of the North Boundary Containment System.

Trichloroethylene plumes occur in western portions of RMA, and extend in the Western Tier pathway from the southern RMA boundary in Section 9 northward through Sections 4 and 33. This plume merges in Section 4 with a second plume that occurs in the Rail Classification Yard pathway (Figure 4.2-16). Concentration of trichloroethylene in the Western Tier plume range from <1.3 ug/l to over 50 ug/l (Well 09014). Concentrations in the Railyard plume range from 3.62 ppb in Well 04042 to 156 ug/l in Well 04049.

Alluvial cluster wells in this area illustrate depth distribution of trichloroethylene. Cluster Wells 04046 (deeper well) and 04047 (shallower well) contained 2.89 and 3.78 ug/l trichloroethylene, respectively. At an alluvial cluster site that includes Wells 04042 (shallower) and 04043, 3.62 and 2.49 ug/l trichloroethylene were detected, respectively. Trichloroethylene is denser than water and would occur near the bottom of an aquifer if concentrations were great enough for free phase trichloroethylene to be present. Concentrations in these two cluster sites are not high enough to exhibit this density differentiation.

Detections were noted in 38 of the 65 EPA western off-post wells sampled between December 1985 and March 1987 (Figure 4.2-16). These detections ranged from 5 ug/l to over 100 ug/l. These data are non-contemporaneous and are contoured to show the occurrence of groundwater contamination in the off-post area and to illustrate on-post-off-post contaminant relationships.

Maximum trichloroethylene plume length in the Western Tier area is over 15,000 ft, with the apparent merged plume width greater than 4,000 ft. Plumes occur in areas of saturated alluvium. The source for the Rail Classification Yard pathway plume is the railyard, while the Western Tier plume appears to originate from the Motor Pool Area, Building 627. A third plume flows from an off-post source southwest of RMA to the South Adams County Wells. This third plume does not enter on-post.

Two wells contained detectable levels of trichloroethylene in the First Creek pathway (Figure 4.2-16). Other isolated trichloroethylene detections occur at Wells 34508 (1.1 ug/l), unconfined Well 27049 (3.52 ug/l), and off-post Wells CIII (5.41 ug/l) and 37359.

Denver Aquifer

Of the Denver Formation wells sampled during the Third Quarter FY87, 141 were from confined and 35 were from unconfined wells. There were 10 unconfined Denver Formation trichloroethylene detections. Detections of trichloroethylene occurred in 12 confined Denver Formation well samples and were considered by zone to determine whether plumes occurred. Viable explanations for the presence of trichloroethylene plumes could not be identified in confined portions of the Denver Formation. Table 4.2-14 includes a list of confined Denver Formation trichloroethylene detections by zone and aquifer.

Based on Third Quarter FY87 results, trichloroethylene was detected above the certified reporting limits in samples from confined Denver Formation wells screened in zones A, 1u, 1, 2, 3 and 4. Point plots included in Appendix D show trichloroethylene concentration and distribution in each zone.

All trichloroethylene detections within zone VC/VCE occurred in unconfined Denver Formation wells. Only four wells sampled from zones A, 1u and 1 contain detectable levels of trichloroethylene and three were from confined Denver Formation wells (Table 4.2-14). These wells were 02035 (5.42 ug/l) in zone A, 26066 (3.98 ug/l) in zone 1 and 35016 in zone 1u (2.55 ug/l). Wells 02035 and 35016 occur near or in areas of alluvial trichloroethylene that may have influenced Denver Formation trichloroethylene occurrence.

Seven wells screened in sandstone zone 2 contained detectable levels of trichloroethylene, although five of these were unconfined Denver wells. Wells 23218 (4.43 ug/l) and 37387 (8.68 ug/l) were the only confined Denver Formation zone 2 wells that contained detections. Both sites occur near areas of alluvial contamination.

Six wells in zones 3 through 7 contained detectable levels of trichloroethylene, and all were screened in the confined portion of the Denver Formation. Wells 23219 (1.33 ug/l), 37376 (1.38 ug/l) and 37379 (1.37 ug/l) are screened in zone 3. Wells 27054 (1.24 ug/l), 37372 (2.83 ug/l), and 37388 (1.83 ug/l) are screened in Denver Formation zone 4.

4.2.8.4 Tetrachloroethylene

Tetrachloroethylene analyses were conducted on a total 473 groundwater samples collected from wells screened in both the alluvial/unconfined and Denver Formation aquifers during the Third Quarter FY87 sampling program. A total of 73 detections were found, with concentrations ranging from 0.82 to 926 ug/l and a median concentration of 6.67 ug/l. The following discusses historical tetrachloroethylene occurrences, as well as plume configuration in the alluvial/unconfined and Denver Formation aquifers. Unconfined Flow System tetrachloroethylene plumes are shown in Figure 4.2-17 and Denver Formation tetrachloroethylene point plots are included in Appendix D. Alluvial, confined Denver Formation, and unconfined Denver Formation tetrachloroethylene detections are summarized in Table 4.2-5.

Historical Water Quality Data

Tetrachloroethylene is a solvent that was used at RMA in the laundry and clothing treatment plant Building 314. Tetrachloroethylene has generally not been included in analytical suites until the 1980s. Initial Screening Program distribution plots show tetrachloroethylene at RMA in the Basin A - South Plants area, the Basin F - North Boundary Containment System area, the Basin A Neck area, and the Western Tier-Railyard area. Concentrations were greatest in the southern Basin A area of southwest Section 36 and the area immediately downgradient of Basin F in Northern Section 26 and southern Section 23. Concentrations in the Basin A Neck area were approximately 10 ug/l. In the Western Tier, two separate areas of low level contamination existed in Section 9 and in Section 4 through Section 33. Low level Denver Formation occurrences of tetrachloroethylene were present in Section 26 near the Basin C area and in the South plants area of Section 2.

Unconfined Flow System

Of the 332 groundwater samples collected from the Unconfined Flow System and analyzed for tetrachloroethylene, 297 were from alluvial and 35 were from unconfined Denver wells. Tetrachloroethylene was detected in 57 of the alluvial and 13 of the unconfined Denver wells. Concentrations ranged from 0.82 to 926 ug/l. The range of certified reporting limits for tetrachloroethylene are 0.08 to 2.8 ug/l. Table 4.2-15 summarizes alluvial and unconfined Denver Formation tetrachloroethylene detections. Major occurrences of tetrachloroethylene were in the Basin A - South Plants - Basin A neck pathways, the Basin F pathway, Northern Off-Post pathway, First Creek pathway, the Western Tier pathway and the western off-post areas (Figure 4.2-1 and 4.2-17). Isolated detections of tetrachloroethylene were also found on and off-post RMA

The tetrachloroethylene plume within the Basin A - South Plants - Basin A Neck pathways extends from the Basin A - South Plants area southeast into Section 1, southwest into Section 2, northeast into unconfined Denver Formation in Section 36 and into the Basin A Neck area (Figure 4.2-17). Concentrations within this plume range from 2.31 ug/l in unconfined Well 01007 to 184 ug/l in unconfined Well 36056. The highest concentrations occur in the extreme southwest Basin A area (36001) and north through the central portion of Basin A. Lower concentrations occur in the southern areas in Sections 1 and 2. Concentrations decrease to less than the certified reporting limit through the

Table 4.2-15 Summary of Analytical Results for Tetrachloroethylene for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm

Geologic Unit	No. of Samples Analyzed	No. of Detections	Range of Detection (ug/l) ¹	No. of EDLs*	Range of EDLs (ug/l) ¹
ALLUVIUM	297	57	0.82 - 926	3	123 - 650
DENVER					
B, Unconfined	0	0	--	0	--
B, Confined	3	0	--	0	--
VC/VCE, Unconfined	7	4	2.31 - 184	0	--
VC/VCE, Confined	0	0	--	0	--
A, Unconfined	3	1	6.1	0	--
A, Confined	28	1	3.06	0	--
1u, Unconfined	0	0	--	0	--
1u, Confined	13	0	--	0	--
1, Unconfined	8	1	5.33	1	26
1, Confined	16	1	5.70	0	--
2, Unconfined	13	7	3.86 - 70.1	0	--
2, Confined	28	1	1.54	0	--
3, Unconfined	4	0	--	0	--
3, Confined	20	0	--	0	--
4, Unconfined	0	--	0	--	0
4, Confined	20	0	--	0	--
5, Confined	9	0	--	0	--
6, Confined	2	0	--	0	--
7, Confined	2	0	--	0	--

¹ Micrograms per liter
* Elevated detection limit

Source: ESE, 1988.

Basin A Neck area. The plume is over 5,000 ft long and exhibits a maximum width of less than 3,000 ft. The plume also occurs mainly in an area of saturated alluvium, except in northern portions of Section 1 (Figure 4.2-17) or along the northern edge of Basin A. Apparent plume source was the general South Plants area with potential contribution from sources in Section 36.

Another tetrachloroethylene plume begins in the northern portion Section 26 and extends along the Basin F pathway to the North Boundary Containment System (Figure 4.2-17). Concentrations of tetrachloroethylene in this plume range from 2.83 ug/l in Well 23007 to 926 ug/l in Well 26133. The highest concentrations occur downgradient of Basin F in the Basin F pathway, but are generally lower than 50 ug/l. As previously discussed, tetrachloroethylene also occurs in unconfined wells immediately downgradient of the North Boundary Containment System and may derive a very minor contribution by flow under the boundary through the upper Denver Formation (ESE, 1988e, RIC#88344R02). The plume is approximately 5,000 ft long and about 2,500 ft wide at its widest point. The plume occurs in areas of saturated alluvium, except in the northern portion of Section 26 where it occurs in the unconfined Denver Formation below unsaturated alluvium.

The tetrachloroethylene plume in the Northern Off-Post pathway occurs north of the North Boundary Containment System through Section 13 off-post (Figure 4.2-17) and merges with a plume in the First Creek Off-Post pathway. Concentrations in the Northern Off-Post pathway range from 3.86 ug/l in unconfined Well 23203 to 115.0 ug/l in Well 37344. At its widest point, the plume extends 2,000 ft and exhibits a maximum length of approximately 7,000 ft.

Tetrachloroethylene also exists within the First Creek Off-Post pathway (Figures 4.2-1 and 4.2-17). Concentrations range from 8.96 ug/l in Well 37369 to 45.4 ug/l in Well 37309. The plume area is approximately 1,000 ft wide and 2,000 ft long, and merges with the Northern Off-Post plume north of the North Boundary Containment System (Figure 4.2-17). Both plumes occur in locations of saturated alluvium and are the remnant plumes separated from on-post plume occurrences by operation of the North Boundary Containment System. However, Figure 4.2-17 indicates that tetrachloroethylene occurring near the North Boundary Containment System is possibly influenced in a very minor sense by flow under the boundary. This situation is further discussed in the Task 36 Report (ESE, 1988e, RIC#88344R02).

The tetrachloroethylene plume in the Western Tier occurs entirely within Section 4 in the Western Tier pathway. Concentrations range from 2.01 ug/l in Well 04004 to 4.76 ug/l in Well 04045. The plume is about 5,000 ft long (Figure 4.2-17) with a maximum width of approximately 1,000 ft.

Fifteen of the 65 EPA wells show detectable levels of tetrachloroethylene west of Quebec Street with concentrations ranging from 5 to 120 ug/l. The data collected between December 1985 and March 1987 have shown the existence of tetrachloroethylene in the groundwater in that area. The tetrachloroethylene plume in the on-post Western Tier pathway occurs in saturated alluvium and appears to be influenced by off-post sources to the south and west.

Isolated tetrachloroethylene detections occur to the north and northwest off-post of RMA, and Sections 9 and 26 on-post. These concentrations are generally lower than the highest tetrachloroethylene certified reporting limit and could not be included in plume construction. A total of 10 wells were considered isolated with unconfined Well 26071 displaying the highest concentrations, at 5.3 ug/l tetrachloroethylene.

Denver Aquifer

Of the 141 total confined Denver Formation wells sampled during the Third Quarter FY87 sampling period only three confined Denver Formation tetrachloroethylene occurrences were detected. Table 4.2-15 includes a list of Denver Formation tetrachloroethylene detections by zone and aquifer system.

Based on Third Quarter FY87 analytical results, tetrachloroethylene was detected above certified reporting limits in samples collected from wells screened in confined portions of Denver Formation zones A, 1 and 2.

Tetrachloroethylene was detected in four samples taken from unconfined portions of the VC/VCE unit of the Denver Formation. It was not detected in confined portions of the VC/VCE zone. Only two wells screened in confined portions of the Denver Formation contained detectable concentrations of tetrachloroethylene, out of the 62 total wells sampled in these zones (Table 4.2-15). They were Wells 02035 (3.06 ug/l) screened in zone A and 26066 (5.77 ug/l) screened in zone 1. Wells screened in confined portions of zone

It did not contain tetrachloroethylene. Well 26066 occurs in an area where the overlying Unconfined Flow System is contaminated. Well 02035 occurs in an area where tetrachloroethylene has been sporadically detected at very low levels in the overlying Unconfined Flow System (less than in Well 02035), indicating that no definitive correlation between the Unconfined Flow System and Denver Formation tetrachloroethylene exists at this location.

Half of the 16 tetrachloroethylene detections within Denver Formation wells occurred in zone 2; although 7 of the 8 detections were from wells included in the unconfined zone 2. Well 26061 is screened in the confined portion of zone 2, and contained 1.54 ug/l tetrachloroethylene. This area of contamination in zone 2 occurs near an area of Unconfined Flow System tetrachloroethylene contamination. Well 26061 occurs near zone 2 subcrop where thin confining layers between the zone and the alluvium are potentially thin or absent, allowing for greater downward groundwater migration. There were no detections of tetrachloroethylene in 53 wells sampled from confined Denver Formation zones 3, 4, 5, 6 and 7.

4.2.9 DBCP

Analyses for the compound DBCP were performed on 440 groundwater samples collected from alluvial and Denver Formation wells during Third Quarter of FY87. DBCP concentrations ranging from 0.146 to 278 ug/l were detected in 68 of the 440 samples analyzed. The distribution of DBCP in the Unconfined Flow System is illustrated on the plume map presented in Figure 4.2-18. DBCP was detected in confined Denver Formation groundwater only within the A, 2 and 4 zones. These detections are shown on the concentration point plots presented in Appendix D. The alluvial/unconfined aquifer plume map and Denver Formation point plots are discussed in Sections 4.2.9.2 and 4.2.9.3 below. Alluvial, unconfined Denver Formation, and confined Denver DBCP detections are summarized in Table 4.2-5.

4.2.9.1 Historical Water-Quality Data

DBCP is a soil fumigant that was manufactured at RMA from 1955 to 1976 and was discharged with liquid wastes to RMA disposal basins (Ebasco, 1988b, RIC#88357R01). Historically, DBCP has been detected in both the alluvium and the Denver Formation at

RMA. According to Initial Screening Program data, the highest concentrations of DBCP in alluvial groundwater were observed in the South Plants area, the southern portion of Basin A, an area extending from southeastern Section 4 to the Irondale Boundary Control System and an area north of Basin F in Sections 23 and 26. Concentrations of DBCP in these areas generally ranged from 1.5 to 10 ug/l. Within the Denver Formation, only 2 of 144 groundwater samples analyzed during the Initial Screening Program contained DBCP. The concentrations of DBCP detected were 0.14 ug/l (Well 02039) and 0.75 ug/l (Well 06003).

The distribution of DBCP, based on analyses performed between 1979 and 1983, indicated that concentrations in excess of method detection limits were observed extending from the South Plants-Basin A area through Basins A, B, C, D, E and F to the Northwest Boundary Containment System and the North Boundary Containment System within the alluvial aquifer (MKE unpublished data, 1986). Within the Denver Formation, concentrations of DBCP ranging from 1.0 to 5.5 ug/l were observed in 8 wells located in Sections 26 and 35 near Basins B, C and D.

4.2.9.2 Unconfined Flow System

During Third Quarter FY87, 299 groundwater samples were collected from alluvial/unconfined wells and were analyzed for DBCP. Of these, 265 samples were collected from wells screened within alluvium and 34 samples were collected from wells completed within the Unconfined Flow System in the uppermost Denver Formation. DBCP concentrations ranging from 0.146 to 278.00 ug/l were observed in 63 of the 299 groundwater samples analyzed. A summary of analytical results for DBCP in alluvial and Denver Formation wells completed within the confined groundwater flow system is presented in Table 4.2-16. The certified reporting limit used for DBCP analyses during Third Quarter FY87 was 0.130 ug/l. Concentrations in excess of 2.0 ug/l were observed in the South Plants Basin A area (Sections 1 and 36), between Basin F and the North Boundary Containment System (Sections 23, 24 and 26) and downgradient of the RMA northern boundary in off-post Sections 12 and 13.

The distribution of DBCP is shown on the plume map presented in Figure 4.2-18. Three DBCP plumes were identified; the largest occurring in the Basin F pathway and extending from Basin F to the RMA north boundary and also occurring in the Northern Off-Post

Table 4.2-16 Summary of Analytical Results for DBCP for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm

Geologic Unit	No. of Samples Analyzed	No. of Detections	Range of Detection (ug/l) ¹	No. of EDLs*	Range of EDLs (ug/l) ¹
ALLUVIUM	264	55	0.146 - 278.0	0	--
DENVER					
B, Unconfined	0	0	--	0	--
B, Confined	3	0	--	0	--
VC/VCE, Unconfined	7	1	1.55	0	--
VC/VCE, Confined	0	0	--	0	--
A, Unconfined	3	0	--	0	--
A, Confined	28	1	0.517	0	--
Iu, Unconfined	0	0	--	0	--
Iu, Confined	13	0	--	0	--
I, Unconfined	8	1	0.747	0	--
I, Confined	16	0	--	0	--
2, Unconfined	13	6	0.609 - 5.57	0	--
2, Confined	28	2	0.379 - 0.779	0	--
3, Unconfined	4	0	--	0	--
3, Confined	20	0	--	0	--
4, Unconfined	0	0	--	0	--
4, Confined	20	2	0.191 - 0.207	0	--
5, Confined	9	0	--	0	--
6, Confined	2	0	--	0	--
7, Confined	2	0	--	0	--

¹ Micrograms per liter
* Elevated detection limit

Source: HLA, 1988.

pathway off-post into Section 11. A second plume extended from the Basin A pathway along the Basin A Neck pathway to near the Northwest Boundary Containment System and a third occurred in the Railroad Classification Yard pathway, extending to the Irondale Boundary Control System.

As shown in Figure 4.2-18, isolated detections of DBCP were observed in Sections, 1, 3, 22 and 28. Except for the isolated detection noted in Section 3, these occurrences may be related to the three identified DBCP plumes discussed above. The contamination observed in northeastern Section 3 does not appear to be related to any of these plumes and the source for this occurrence is not known.

The largest plume shown in Figure 4.2-18 extends north from Basin F to southeastern Section 11 off-post. The plume trends northeast from Basin F for approximately 5,000 ft to the northwest quadrant of Section 24.

A second plume occurs in the off-post area where it acquires a north-northeast direction and follows the Northern Off-Post pathway for approximately 7,000 ft to the northern boundary of Section 13. North of Section 13, the plume continues along the northern off-post pathway for approximately 3,500 ft through the southwest corner of Section 12 and into the southeast portion of Section 11. The maximum evident extent of the plume downgradient of the northern RMA boundary is 8,000 ft.

The plume ranges in width from approximately 1,100 to 3,500 ft upgradient of the North Boundary Containment System, and from approximately 700 to 1,100 ft downgradient of the North Boundary Containment System. Immediately upgradient of the North Boundary Containment System, the DBCP plume appears to spread laterally, dominantly to the east (Figure 4.2-18). This condition indicates that the plume is generally contained along the eastern extent of the North Boundary Containment System. However, DBCP concentrations detected directly downgradient of the pilot portion of the system may be influenced by minor transport beneath the barrier through the Denver Formation or are more likely representative of residual contamination. Contaminant trends in and around the North Boundary Containment System have been discussed further in the Task 36 Draft Final Report (ESE, 1988e, RIC#88344R02).

DBCP concentrations within the plume described above range from 0.172 to 35.40 ug/l, with the highest detection reported from Well 26133 located approximately 700 ft northeast of Basin F. Off-post, the highest concentration detected was 10.60 ug/l in Well 37344 located in the southwest corner of Section 12.

The second plume of DBCP shown in Figure 4.2-18 occurs in the Basin A pathway and extends into the Basin A Neck pathway. The plume trends north from the South Plants-Basin A area and then northwest along the Basin A Neck pathway to south-central Section 22. The plume extends approximately 15,000 ft in length and ranges in width from approximately 500 ft in the Basin A Neck paleochannel to approximately 3,000 ft in Section 36. The plume appears to be largely contained by the Basin A Neck paleochannel in Sections 35 and 26 and eastern Section 27 but exhibits less channel control in northern Section 27. As indicated in Figure 4.2-18, the southern extent of this plume was interpreted to extend slightly south and east of the highest reported Third Quarter FY87 detection based on Task 4 Initial Screening Program, MKE and USATHAMA historical data.

DBCP concentrations within the plume range from 0.146 to 278.00 ug/l. The highest detection reported was from Well 36001 located in the southwest corner of Section 36. No concentrations higher than 0.500 ug/l were reported within the plume outside of the South Plants-Basin A area. The main source of DBCP in this plume was probably the general South Plants - southern Basin A area with possible contributions from Basins B, C and D. The third plume shown in Figure 4.2-18 trends northwest from the Railroad Classification Yard in southwestern Section 3 to the Irondale Boundary Control System. The plume extends approximately 9,000 ft and ranges from 1,000 to 1,400 ft in width. DBCP concentrations within the plume range from 0.416 to 45.40 ug/l. The highest DBCP concentration observed within the plume was 45.4 ug/l in Well 03523 located within the Railroad Classification Yard in southwestern Section 3. The lowest concentration observed was 0.42 ug/l in Well 33039 located immediately upgradient of the Irondale Containment System. DBCP spills within the Railroad Classification Yard were the likely source for this contamination.

4.2.9.3 Denver Aquifer

During Third Quarter FY87, 176 groundwater samples were collected from Denver Formation wells and were analyzed for DBCP. Of these, 35 Denver Formation wells were

completed within the Unconfined Flow System. The analytical results from these 35 wells are summarized on Table 4.2-16. These results were contoured and discussed in conjunction with the Unconfined Flow System in the preceding section. The results of DBCP analyses performed on samples collected from the remaining 141 confined Denver Formation wells are also summarized on Table 4.2-16.

Based on Third Quarter FY87 analytical results, DBCP concentrations above certified reporting limits were observed in samples collected from confined Denver Formation wells completed only within the zones A, 2, and 4 (Table 4.2-16). The locations of wells completed within each of these zones, and detected DBCP concentrations are shown on the point plots presented in Appendix D.

The single DBCP detection observed in the A zone (Well 01036) may have been associated with the isolated Unconfined Flow System detection observed in Well 01041. Both Wells 01036 and 01041 are located southeast of the South Plants. Within Denver zone 2, isolated DBCP detections were observed in Wells 23218 and 37387. The contamination noted in Well 23218, located immediately downgradient of the North Boundary Containment System, may have been associated with the DBCP plume identified in the overlying Unconfined Flow System and may indicate contaminant transport through the Denver Formation beneath the pilot portion of the North Boundary Containment System. The DBCP concentration noted in Well 37387 and in Denver zone 4 Wells 37372 and 37380 show no clear relationship to the DBCP distribution noted in the overlying saturated alluvium. The DBCP concentrations in these wells, however, may be a result of possible migration from the saturated alluvium into the Denver Formation in upgradient on-post areas.

DBCP was not detected in groundwater samples obtained from wells screened in the confined portions of the remaining Denver Formation zones. The locations of wells completed within these units are shown on the well location maps presented in Plate 4.

4.2.10 Dicyclopentadiene

Analyses for the compound dicyclopentadiene were performed on 436 groundwater samples collected from alluvial and Denver Formation wells during the Third Quarter of FY87. Dicyclopentadiene concentrations ranging from 10.7 to 1,200 ug/l were detected in 31 of the 436 samples analyzed. The distribution of dicyclopentadiene in the Unconfined Flow

System is illustrated on the plume map presented in Figure 4.2-19. Dicyclopentadiene was not detected in confined Denver Formation groundwater, although five elevated reporting limits resulting from sample dilution were observed within the confined Denver Formation with reporting limits ranging from 16.2 to 21.6 ug/l. The Unconfined Flow System plume map is discussed in Section 4.2.10.2 below. Alluvial, unconfined Denver Formation, and confined Denver Formation dicyclopentadiene detections are summarized in Table 4.2-5.

4.2.10.1 Historical Water-Quality Data

Historically dicyclopentadiene has been detected in both alluvial and Denver Formation groundwater at RMA. Dicyclopentadiene was detected in 7 of 147 alluvial groundwater samples analyzed during the Initial Screening Program at concentrations ranging from 13.3 to 571 ug/l. The highest dicyclopentadiene concentration within the alluvial aquifer was observed in Well 26133, located downgradient of Basin F. During the Initial Screening Program, detected concentrations of dicyclopentadiene were observed extending from Basin F into southern Section 23 and at isolated locations in Sections 3, 24, 35 and 36. The highest isolated detection was 70.3 ug/l in Well 36001.

Dicyclopentadiene was detected in three of 144 Denver aquifer water samples analyzed during the Initial Screening Program with concentrations ranging from 10.3 to 1,510 ug/l. The highest concentration was in Well 01014, located within the South Plants, in west-central Section 1. According to the Initial Screening Program report, dicyclopentadiene occurrences in the Denver Formation have no correlation to dicyclopentadiene occurrences in the alluvial aquifer.

The historical data collected prior to the Initial Screening Program indicate that dicyclopentadiene occurs from Basin F to the RMA northern border; widespread dicyclopentadiene distribution in Sections 1, 35 and 36; and isolated areas of dicyclopentadiene in Sections 22, 27, 18, 33 and 34. These patterns were not confirmed in the Initial Screening Program data. Comparison of the Initial Screening Program alluvial groundwater distribution to the historical data indicated significant discrepancies in the dicyclopentadiene distributions.

Comparison of Denver Formation water-quality data from Initial Screening Program to historical data also indicated differences in the distribution of dicyclopentadiene.

Dicyclopentadiene patterns were identified in the historical data collected prior to the Initial Screening Program in Sections 1, 22, 23, 24 and 26 but these patterns were not identified in the Initial Screening Program Denver data. Isolated detections were also identified in Sections 19, 20, 28 and 33 but were not confirmed by the Initial Screening Program.

Historical alluvial groundwater data presented in the Spaine report (1984) identified dicyclopentadiene concentrations associated with the South Plants area, Basin A and the Basin A Neck area. A dicyclopentadiene pattern was also identified immediately downgradient of Basin F and extending to the north boundary of RMA. Comparison of the Spaine data to the Initial Screening Program alluvial data shows wider distribution and significantly higher concentrations of dicyclopentadiene in groundwater samples analyzed during the 1984 investigation. Reasons for the differences are not known.

4.2.10.2 Unconfined Flow System

During Third Quarter FY87, 298 groundwater samples were collected from alluvial and unconfined Denver Formation wells and were analyzed for dicyclopentadiene. Of these, 262 samples were collected from wells screened within alluvium and 35 samples were collected from wells completed within the unconfined groundwater flow system in the uppermost Denver Formation. Dicyclopentadiene concentrations ranging from 10.7 to 1,200 ug/l were observed in 31 of the 297 groundwater samples analyzed. A summary of analytical results for dicyclopentadiene in alluvial and Denver Formation wells completed within the unconfined groundwater flow system is presented in Table 4.2-17. The method detection limit used for dicyclopentadiene analyses during the Third Quarter FY87 sampling event was 9.31 ug/l. Concentrations in excess of 50 ug/l were observed in the Basin F pathway between Basin F and the North Boundary Containment System (Sections 23 and 26) downgradient of the North Boundary in the First Creek Off-Post pathway (Sections 13 and 14) and within the Basin A Neck pathway (Section 35).

The distribution of dicyclopentadiene in the Unconfined Flow System is shown on the plume map presented in Figure 4.2-19. Four dicyclopentadiene plume areas were also identified. The largest extends in the Basin F pathway from Basin F to the North Boundary Containment System, and reoccurs downgradient of the North Boundary

Table 4.2-17 Summary of Analytical Results for DCPD for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm

Geologic Unit	No. of Samples Analyzed	No. of Detections	Range of Detection (ug/l) ¹	No. of EDLs [*]	Range of EDLs (ug/l) ¹
ALLUVIUM	262	25	10.7 - 1,200	5	16.2 - 21.6
DENVER					
B, Unconfined	0	0	--	0	--
B, Confined	3	0	--	0	--
VC/VCE, Unconfined	7	0	--	0	--
VC/VCE, Confined	0	0	--	0	--
A, Unconfined	3	0	--	0	--
A, Confined	28	0	--	1	16.2
1u, Unconfined	0	0	--	0	--
1u, Confined	13	0	--	1	16.2
1, Unconfined	8	1	16.6	0	--
1, Confined	16	0	--	0	--
2, Unconfined	13	5	49.9 - 256	0	--
2, Confined	28	0	--	1	16.2
3, Unconfined	4	0	--	0	--
3, Confined	19	0	--	1	21.6
4, Unconfined	0	0	--	0	--
4, Confined	20	0	--	0	--
5, Confined	9	0	--	1	21.6
6, Confined	2	0	--	0	--
7, Confined	2	0	--	0	--

¹ Micrograms per liter
^{*} Elevated detection limits

Source: HLA, 1988.

Containment System in the First Creek Off-Post pathway. The second extends from northwestern Basin A through the Basin A Neck to the southeastern edge of Basin C, and the third inferred plume extends from the South Plants into the middle of Basin A. In the third area (southwestern Section 36), dicyclopentadiene may exist but its presence could not be confirmed by Third Quarter FY87 analytical results because of the lack of sampling in the specific area. Historical data from Task 4 Initial Screening Program, MKE, and USATHAMA were reviewed to assess the historical trend of dicyclopentadiene in this area. This review indicated dicyclopentadiene concentrations have consistently been detected in the wells within the contoured area. The fourth area, indicated by unpublished data (MKE, 1988), is located near South Plants and appears to be moving toward the south. As also shown in Figure 4.2-19, five elevated reporting limits resulting from sample dilutions were observed in isolated areas in Sections 22, 23, 26 and 36 with certified reporting limits ranging from 16.20 to 21.6 ug/l.

The largest plume area shown in Figure 4.2-19 extends from Basin F to the North Boundary Containment System and then occurs downgradient northwest of the RMA boundary to the center of Section 14 off-post. Basin F may be a possible source of the dicyclopentadiene identified within this pathway. The plume trends northeast from Basin F for approximately 4,500 ft to east central Section 23, shifts to the north and continues for approximately 2,000 ft to the North Boundary Containment System. A plume then appears to continue downgradient of the RMA north boundary extending approximately 4,000 ft along the off-post First Creek pathway in Sections 13 and 14.

The Basin F dicyclopentadiene plume is approximately 11,500 ft in length and ranges from 1,100 to 1,900 ft in width. In general, the plume is laterally more extensive upgradient of the North Boundary Containment System than downgradient of the system and appears to spread east along the soil-bentonite barrier (Figure 4.2-19). Dicyclopentadiene concentrations noted in wells located immediately downgradient of the North Boundary Containment System are significantly lower than those observed in upgradient wells. However, approximately 1,500 ft north of the North Boundary Containment System, dicyclopentadiene concentrations are similar to concentrations observed immediately upgradient of the North Boundary Containment System. This condition implies that contaminant transport may be occurring within the underlying Denver Formation but at a very minor rate. Contamination is more likely representative of residual contamination.

Contaminant trends in and around the North Boundary Containment System are discussed further in the Task 36 Draft Final Report (ESE, 1988c, RIC#88344R02).

Dicyclopentadiene concentrations within the plume range from 10.7 to 1,200 $\mu\text{g/l}$ with the highest detection reported for Well 23049 located adjacent to Section 26 directly downgradient of Basin F. Off-post, the highest detection observed within the plume was 475 $\mu\text{g/l}$ in Well 37209 located about 1,300 ft directly north of the RMA boundary.

The second plume of dicyclopentadiene shown in Figure 4.2-19 trends northwest from the northwest corner of Basin A along the Basin A Neck to the southeast corner of Basin C. This plume is much smaller than the plume previously discussed near Basin F and its delineation is based partially on historical data. This smaller plume extends approximately 3,100 ft in length and 600 ft in width. Based on Third Quarter 1987 data, the only dicyclopentadiene detection noted within the area of this plume occurred within Well 35065. However, historical data from Task 4, MKE (1986, unpublished data) and USATHAMA show that dicyclopentadiene detections have been noted in Wells 35007, 35046, 35047, 35065, 36020, 36040 and 36041. This implies the presence of dicyclopentadiene concentrations within this area. The probable sources for this dicyclopentadiene plume included Basin A and chemical sewers.

The third plume shown in Figure 4.2-19 in southwest Section 36 was inferred entirely from historical data. The extent of this plume is based on historical dicyclopentadiene concentrations detected in the Wells 01502, 01503, 01504, 01505, 01506, 36001, 36054, 36056, 36058 and 36076. Well 36001, which was not analyzed for dicyclopentadiene during Third Quarter of FY87, has consistently shown dicyclopentadiene detections during past analyses. Probable sources for dicyclopentadiene contamination in this area included the South Plants-Basin A area.

4.2.10.3 Denver Aquifer

During Third Quarter FY87, 174 groundwater samples were collected from Denver Formation wells, and analyzed for dicyclopentadiene. Of these, 35 Denver Formation wells were completed within the unconfined groundwater flow system. The analytical results from these 35 wells are summarized on Table 4.2-17. These results were contoured and discussed in conjunction with the Unconfined Flow System in the preceding section. The

results of dicyclopentadiene analyses performed on samples collected from the remaining 139 confined Denver Formation wells are summarized on Table 4.2-17.

Based on Third Quarter FY87 analytical results, dicyclopentadiene concentrations above certified reporting limits were not observed in any samples collected from confined Denver Formation wells (Table 4.2-17). Well 01014 which has consistently shown high dicyclopentadiene concentrations was not sampled during the Third Quarter FY87.

4.2.11 Diisopropylmethyl Phosphonate

Analyses for the compound diisopropylmethyl phosphonate were performed on 430 groundwater samples collected from alluvial and Denver Formation wells during the Third Quarter FY87. Diisopropylmethyl phosphonate concentrations ranging from 11.9 to 12,100 ug/l were detected in 132 of the 430 samples analyzed. The distribution of diisopropylmethyl phosphonate in the Unconfined Flow System is illustrated on the plume map presented in Figure 4.2-20. Diisopropylmethyl phosphonate was detected in confined Denver Formation groundwater only within the zones A, 1u, 1, 2, 3 and 5. These detections are shown on the concentration point plots presented in Appendix D. The Unconfined Flow System and Denver Formation point plots are discussed in Sections 4.2.11.2 and 4.2.11.3 below. Alluvial, unconfined Denver Formation, and confined Denver Formation diisopropylmethyl phosphonate detections are summarized in Table 4.2-5.

4.2.11.1 Historical Water Quality Data

Diisopropylmethyl phosphonate is a byproduct in the manufacture of GB nerve gas (Ebasco, 1988b, RIC#88357R01). Historical data indicate that diisopropylmethyl phosphonate has been detected in both alluvial and Denver Formation groundwater at RMA. During the Task 4 Initial Screening Program, the distribution of diisopropylmethyl phosphonate in the alluvial aquifer was observed to extend from Basin A, through Basins B through F, to the RMA north boundary in northern Section 23 and northwestern Section 24. Diisopropylmethyl phosphonate was detected at concentrations in excess of 1000 ug/l in alluvial groundwater during the Initial Screening Program in the Basin A/Basin A Neck pathways (Section 36), downgradient of Basins C, D and F in the Basin F pathway area (Sections 23 and 26) and along the RMA north boundary (Section 23).

Diisopropylmethyl phosphonate was detected in Denver Formation groundwater during the Initial Screening Program in an area extending from the Basin A Neck, through Basin B, to the northern portion of Basin C. Concentrations in excess of 1,000 ug/l were observed downgradient of Basin B and in northern Basin C. An isolated detection of diisopropylmethyl phosphonate in concentrations greater than 2100 ug/l observed during the Initial Screening Program in southeastern Section 35 was not confirmed in subsequent monitoring events (Task 4 Third and Fourth Quarters and Task 44) and, therefore, is not considered representative of Denver Formation groundwater in this area.

4.2.11.2 Unconfined Flow System

During Third Quarter FY87, 294 groundwater samples were collected from alluvial and unconfined Denver Formation wells and were analyzed for diisopropylmethyl phosphonate. Of these, 259 samples were collected from wells screened within alluvium and 35 samples were collected from wells completed within the unconfined groundwater flow system in the uppermost Denver Formation. Diisopropylmethyl phosphonate concentrations ranging from 11.9 to 12,100 ug/l were observed in 121 of the 294 groundwater samples analyzed. A summary of analytical results for diisopropylmethyl phosphonate in alluvial and Denver Formation wells completed within the Unconfined Flow System is presented in Table 4.2-18. The certified reporting limit used for diisopropylmethyl phosphonate analyses during Third Quarter FY87 was 10.5 ug/l. Concentrations in excess of 1,000 ug/l were observed on-post, within an area extending from Basin A through Basins B, C, D and F to the North Boundary Containment System, and off-post north of RMA within the First Creek pathway (Section 14), and the Northern pathway (Section 12 and 13).

The distribution of diisopropylmethyl phosphonate in the Unconfined Flow System is shown on the plume map presented in Figure 4.2-20. A diisopropylmethyl phosphonate plume also occurs in an area extending from Basin A through Basin A Neck, through the Basin F pathway, to the RMA north boundary, and it continues off-post along the First Creek off-post pathway and Northern Off-Post pathways to near the South Platte River. Isolated detections of diisopropylmethyl phosphonate were observed on-post in Sections 22 and 23 and off-post in Section 16. Detections exceeding the upper certified reporting limits were not reported for alluvial samples analyzed for diisopropylmethyl phosphonate during Third Quarter FY87 analyses.

Table 4.2-18 Summary of Analytical Results for Diisopropylmethyl Phosphonate for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm

Geologic Unit	No. of Samples Analyzed	No. of Detections	Range of Detection (ug/l) ¹	No. of EDLs*	Range of EDLs (ug/l) ¹
ALLUVIUM	259	102	11.9 - 12,100	0	--
DENVER					
B, Unconfined	0	0	--	0	--
B, Confined	2	0	--	0	--
VC/VCE, Unconfined	7	2	13.2 - 164	0	--
VC/VCE, Confined	0	0	--	0	--
A, Unconfined	3	1	417	0	--
A, Confined	28	1	2,710	0	--
Iu, Unconfined	0	0	--	0	--
Iu, Confined	13	1	5,350	0	--
1, Unconfined	8	4	12.0 - 5,230	0	--
1, Confined	16	4	17.0 - 286	0	--
2, Unconfined	13	11	11.9 - 1,900	0	--
2, Confined	28	3	27.0 - 767	0	--
3, Unconfined	4	1	1,100	0	--
3, Confined	17	1	47.1	0	--
4, Unconfined	0	0	--	0	--
4, Confined	19	0	--	0	--
5, Confined	9	1	27.0	0	--
6, Confined	2	0	--	0	--
7, Confined	2	0	--	0	--

¹ Micrograms per liter
* Elevated detection limit

Source: HLA, 1988.

The main body of the diisopropylmethyl phosphonate plume area shown in Figure 4.2-20 extends approximately 17,000 ft from Basin A to the RMA north boundary, along the First Creek Off-Post pathway approximately 17,000 ft and approximately 19,000 ft along the Northern Off-Post pathway. On-post, the plume ranges in width from about 1,500 ft in Basin A Neck to nearly 4,000 ft in central Section 26. Off-post, the plume averages approximately 1,500 ft in width along each pathway, but reaches a maximum width of nearly 5,000 ft in central Section 14. Diisopropylmethyl phosphonate concentrations within the plume were observed in excess of 1,000 ug/l extending from Basin A to near the North Boundary Containment System and off-post within Sections 12, 13 and 14.

The widespread and continuous nature of the diisopropylmethyl phosphonate distribution necessitates that the plume be described by individual pathways. Diisopropylmethyl phosphonate occurrence in the following pathways are described below:

- o Basin A - Basin A Neck Pathway;
- o Section 26 including Basins C, D, E, and F;
- o Basin F toward the Northwest Boundary Containment System;
- o Basin F Pathway;
- o North Plants Pathway;
- o The North Boundary Containment System; and
- o Off-Post along the First Creek and Northern Off-Post.

As shown in Figure 4.2-20, Basin A appears to be the furthest upgradient source for diisopropylmethyl phosphonate contamination at RMA. The groundwater sample collected from Well 36084, located within the eastern portion of Basin A, contained diisopropylmethyl phosphonate at a concentration of 12,100 ug/l, the highest diisopropylmethyl phosphonate concentration reported during the Third Quarter. Downgradient of Basin A, the diisopropylmethyl phosphonate plume is largely contained within the Basin A neck pathway in northeastern Section 35. However, the Basin A Neck paleochannel appears to have less influence on diisopropylmethyl phosphonate occurrence within the southern portion of Section 26 where the main body of the plume begins to trend north away from the paleochannel. Diisopropylmethyl phosphonate was detected within the paleochannel downgradient of Section 26, however, concentrations were below 50 ug/l.

Concentrations of diisopropylmethyl phosphonate in excess of 1,000 ug/l were observed throughout central Section 26. Because this area is largely underlain by unsaturated alluvium, much of this contamination occurs within the unconfined portion of the uppermost Denver Formation. Denver Formation Wells 26071 and 26041, screened within the unconfined groundwater flow system, recorded the highest diisopropylmethyl phosphonate concentrations within Section 26, at 5,230 and 3,810 ug/l, respectively. Potential sources for diisopropylmethyl phosphonate contamination in Section 26 included basins C, D, E and F as well as chemical sewers. Diisopropylmethyl phosphonate contaminant transport through Section 26 generally follows groundwater flow direction from south to north.

A subsidiary diisopropylmethyl phosphonate plume was observed trending northwest from Basin F to near the Northwest Boundary Containment System in northeastern Section 27. The plume extends approximately 5,000 ft from the body of the main plume and approaches within 200 ft of the Northwest Boundary Containment System. Diisopropylmethyl phosphonate concentrations within the plume range from 12.9 to 58.3 ug/l.

North of Basin F, high concentrations of diisopropylmethyl phosphonate were observed extending in the Basin F Pathway to the North Boundary Containment System. Diisopropylmethyl phosphonate concentrations within this area range from 11.9 to 3,070 ug/l. Diisopropylmethyl phosphonate concentrations greater than 500 ug/l bifurcate around a subtle bedrock high located in central Section 23. East of this bedrock high, the plume trends northeast from Basin F following a shallow bedrock paleochannel for approximately 4,000 ft to east-central Section 23. This east fork then acquires a more northerly direction and continues for approximately 1,800 ft to the North Boundary Containment System. The west fork extends north from Basin F for approximately 3,800 ft into central Section 23. Diisopropylmethyl phosphonate concentrations ranging from 210 to 474 ug/l occur within the elongate divide between these two forks. Lower diisopropylmethyl phosphonate concentrations in the area of the divide could be the result of geologic material in which the sampled wells are screened or due to local variation in groundwater flow in the area of the bedrock high.

Downgradient of the North Plants, another diisopropylmethyl phosphonate plume with an apparent source in north-central Section 25 occurs in the North Plants pathway and joins

the Basin F to North Boundary Containment System portion of the main plume in west-central Section 24. Concentrations range from 11.9 to 448 ug/l along this trend. The plume extends from north-central Section 25 and follows groundwater flow northwest for approximately 2,500 ft.

Immediately upgradient of the North Boundary Containment System the diisopropylmethyl phosphonate plume has an east-west lateral extent of approximately 5,000 ft. Diisopropylmethyl phosphonate concentrations greater than 100 ug/l extend over the entire length of the pilot system and east of D Street for approximately 2,000 ft. Upgradient of the North Boundary Containment System in Section 24 the diisopropylmethyl phosphonate plume appears to spread laterally to the east and is approximately 5,000 ft in width. Downgradient of the North Boundary Containment System, the plume extends only along the western portion of the system for approximately 2,500 ft. This condition indicates that the eastern extension of the North Boundary Containment System probably contains the majority of the diisopropylmethyl phosphonate plume in this area. Diisopropylmethyl phosphonate concentrations detected downgradient of the pilot system may be influenced by very minor contaminant transport beneath the barrier through the unconfined Denver Formation, but are probably more representative of residual contamination. Contaminant trends in and around the North Boundary Containment System are discussed further in the Task 36 Draft Final Report (ESE, 1988e, RIC#88344R02).

Downgradient of the North Boundary Containment System and off-post north of RMA, the diisopropylmethyl phosphonate plume bifurcates around the large area of unsaturated alluvium in western Section 13 and northeastern Section 14 (Figure 4.2-20). The east component trends north-northwest and follows the Northern Off-Post pathway. The western component trends generally northwest and follows the First Creek Off-Post pathway. Both components extend to within 2,000 ft of the South Platte River.

Along the Northern Off-Post pathway, the plume trends north through the western half of Section 13 and then acquires a northwest trend through Sections 11, 2 and 3. The plume extends approximately 19,000 ft from the RMA north boundary, and is shown to terminate near Well 37357, located approximately 2000 ft upgradient of the South Platte River. Concentrations within the plume range from 13.1 to 2030 ug/l, with the highest concentration reported at Well 37391, located in west-central Section 13.

Along the First Creek Off-Post pathway, the western component of the diisopropylmethyl phosphonate plume trends northwest through Section 14, southwest Section 11, northeast Section 10 and central Section 3. The plume extends approximately 17,000 ft from the RMA north boundary and is shown to terminate near Well 37356, located approximately 2,000 ft upgradient of the South Platte River. Observed diisopropylmethyl phosphonate concentrations within the plume range from 41.1 to 2170 ug/l, with the highest concentration reported at Well 37313, located in central Section 14.

Denver Formation Wells 37323 and 37371 in the off-post RMA area have been classified as unconfined. The diisopropylmethyl phosphonate concentration in Well 37323 agrees with the local diisopropylmethyl phosphonate distribution; however, the concentrations in Well 37371 (1,100 ug/l), and adjacent alluvial Well 37370 (278 ug/l), indicate a wide discrepancy between alluvial/unconfined Denver Formation diisopropylmethyl phosphonate concentrations. This discrepancy may be due to the lack of definition of the vertical extent of contamination in Unconfined Flow System.

Isolated diisopropylmethyl phosphonate detections in Third Quarter FY87 sample analyses occur on-post at Wells 23185 (5060 ug/l), 22049 (13.6 ug/l) and 22016 (12.0 ug/l). These wells are located northwest of Basin F in southwest Section 23 and southeast Section 22. Diisopropylmethyl phosphonate occurrences in the three wells are probably related to Basin F.

A single, isolated off-post diisopropylmethyl phosphonate occurrence was observed in Third Quarter FY87 sample analyses. Well 37351 (12.4 ug/l) is located 3500 ft west of the off-post diisopropylmethyl phosphonate plumes and shows no clear relationship to the contoured diisopropylmethyl phosphonate detections.

4.2.11.3 Denver Aquifer

During Third Quarter FY87, 171 groundwater samples were collected from Denver Formation wells and were analyzed for diisopropylmethyl phosphonate. Of these, 35 Denver Formation wells were completed within the unconfined groundwater flow system. The analytical results from these 35 wells are summarized in Table 4.2-18. The results were contoured and discussed in conjunction with the Unconfined Flow System in the preceding section. The results of diisopropylmethyl phosphonate analyses performed on

samples collected from the remaining 136 confined Denver Formation wells are also summarized on Table 4.2-18.

Based on Third Quarter FY87 analytical results, diisopropylmethyl phosphonate concentrations above certified reporting limits were observed in samples collected from confined Denver Formation wells completed only within Denver Formation zones A, 1u, 1, 2, 3, and 5 (Table 4.2-18). The locations of wells completed within each of these zones and detected diisopropylmethyl phosphonate concentrations are shown on the point plots presented in Appendix D.

diisopropylmethyl phosphonate contamination observed in Well 35066 (2710 ug/l), Denver Formation zone A, and 35016 (5350 ug/l), Denver Formation zone 1u, is probably related to alluvial diisopropylmethyl phosphonate contamination in the Basin A/Basin A neck vicinity. Figure 2.4-12 shows potential Denver Formation aquifer interaction in the Basin A Neck area.

The four diisopropylmethyl phosphonate concentrations detected in the Denver Formation zone 1 range from 17.0 to 286 ug/l (Appendix D). Diisopropylmethyl phosphonate contamination in this zone is somewhat localized in the vicinity of Basin C and may be related to contamination in the overlying Unconfined Flow System.

The three diisopropylmethyl phosphonate concentrations detected in the Denver Formation zone 2 range from 27.0 to 767 ug/l (Appendix D). Denver Formation zones 3 and 5 had single diisopropylmethyl phosphonate detections at 47.1 and 27.0 ug/l respectively. In each case the concentration in the Denver Formation zone is less than the concentration in the overlying Unconfined Flow System and may indicate that the Unconfined Flow System is acting as a source of contaminant.

4.2.12 Arsenic

Analyses for arsenic were conducted on 429 groundwater samples collected from both alluvial and Denver Formation wells during the Third Quarter FY87. Detections of arsenic ranged in concentration from 2.56 to 410 ug/l, with a median of 5.82 ug/l. Analyses for arsenic were not conducted in the 65 off-post EPA wells or as part of the Task 38 Western Tier TCE Study. The following section discusses arsenic occurrence in the

alluvial and Denver Formation, with point plots of Denver Formation arsenic detections presented in Appendix D and Unconfined Flow System plume occurrence shown in Figure 4.2-21. Certified reporting limits for arsenic area from 2.5 ug/l to 3.7 ug/l. No attempt has been made to determine background arsenic concentrations, and all detectable concentrations were considered in mapping. Alluvial, unconfined Denver Formation and confined Denver Formation arsenic detections are summarized in Table 4.2-5.

4.2.12.1 Historical Water-Quality Data

Arsenic is a naturally occurring element. It was also a component of Lewisite as well as a byproduct and Lewisite manufacture (Ebasco, 1988b, RIC#88357R01). Historical occurrence maps provided by MKE (unpublished data, 1986) indicated arsenic compound usage and spills occurred within the South Plants area in the early 1940s. Historic arsenic concentrations ranged from 5 to 24 ug/l, and occurred from the Basin A Neck in Section 36 through the Basins C, D and F areas in Section 26. This occurrence continued to the Northwest into Sections 22 and 27 to the Northwest Boundary Containment System. Historic isolated alluvial detections in Section 23 exhibited concentrations from 4.83 to 29.9 ug/l. In the South Plants area, groundwater from wells in Sections 1 and 2 contained between 5 and 21 ug/l of arsenic, with a detection of 18.2 ug/l in the Basin A area.

Initial Screening Program arsenic data exhibited alluvial concentrations between 3.9 and 270 ug/l, with the highest arsenic concentrations occurring in Section 36 (Well 36076). Detections of arsenic between 10 and 50 ug/l also occurred in Sections, 1, 2, 4, 19, 23, 24, 26, 27, 32 and 35. Of the 16 wells analyzed for arsenic in Section 36, 11 showed detectable concentrations of arsenic. These were between 13 and 270 ug/l.

4.2.12.2 Unconfined Flow System

Groundwater samples from a total of 291 Unconfined Flow System wells were analyzed for arsenic in the Third Quarter FY87 sampling event. Of these 257 were alluvial wells and 34 were unconfined Denver Formation wells. Seventy-four of these samples contained detectable concentrations of arsenic. The concentration range of arsenic was from 2.56 ug/l in Well 37368 to 410 ug/l in Well 26041, with a median concentration of 5.67 ug/l. A summary of unconfined Denver and alluvial detections is included in Table 4.2-19. The

Table 4.2-19 Summary of Analytical Results for Arsenic for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm

Geologic Unit	No. of Samples Analyzed	No. of Detections	Range of Detection (ug/l) ¹	No. of EDLs [*]	Range of EDLs (ug/l) ¹
ALLUVIUM	257	66	2.56 - 315	0	--
DENVER					
B, Unconfined	0	0	--	0	--
B, Confined	2	0	--	0	--
VC/VCE, Unconfined	7	2	260.0 - 103	0	--
VC/VCE, Confined	0	0	--	0	--
A, Unconfined	3	1	74.9	0	--
A, Confined	28	4	2.57 - 12.1	0	--
Iu, Unconfined	0	0	--	--	--
Iu, Confined	13	1	7.43	0	--
1, Unconfined	7	3	5.08 - 410	0	--
1, Confined	16	2	6.47 - 6.76	0	--
2, Unconfined	13	2	4.59 - 9.08	0	--
2, Confined	27	3	3.42 - 6.45	0	--
3, Unconfined	4	0	--	0	--
3, Confined	20	0	--	--	--
4, Unconfined	0	0	--	--	--
4, Confined	19	3	4.08 - 8.08	0	--
5, Confined	9	3	4.94 - 22.2	0	--
6, Confined	2	0	--	0	--
7, Confined	2	0	--	0	--

¹ Micrograms per liter
^{*} Elevated detection limit

Source: ESE, 1988.

highest certified reporting limit of 3.7 is the lowest contour interval in Figure 4.2-21. Arsenic plumes occurred in the Basin A/Basin A Neck pathway and the Basin F pathway, which also included a northwest occurrence through Basin F, with minor occurrences in the First Creek Pathway and the Quincy Street pathway. Isolated detections observed occur in the off-post area to the north (Figures 4.2-1 and 4.2-21).

The arsenic plume in the Basin A/Basin A Neck pathways extends from the extreme southern portion of Section 36 through the Basin A area into the Basin A Neck area and continues through the Basin A neck pathway to Section 27 (Figures 4.2-1 and 4.2-21). Arsenic concentrations within this plume range from 3.64 ug/l in Well 36001 at the southern end of the Basin A area to 315 ug/l in Well 36076. Highest concentrations occur in the southern end of Basin A, the central portion of Section 36 area and in the Basin A Neck area. Arsenic concentration in the Basin A Neck area ranges from 5 to 30 ug/l. This plume occurs predominantly in areas of saturated alluvium, but extends into unconfined Denver below unsaturated alluvium in Section 36, and along the margins of the Basin A Neck pathway. The plume is over 15,000 ft long and exhibits a maximum width of approximately 3,000 ft. This plume appears to originate from the southern portion of Section 36.

The main portion of this arsenic occurrence originates in the Basin F East pathway, and extends north along the east edge of Basin F. It merges with a plume in the Basin F pathway that extends to North Boundary Containment System. This plume appears absent in the northeast portion of Section 24; although, relatively higher concentrations occur northeast in Section 23, immediately downgradient of Basin F.

The Basin F arsenic plume also extends to the northwest corner of Section 26. This Basin F - Northwest extension splits, with one portion of the plume extending to the Northwest Boundary Containment System and the other extending through Section 22 around the Northwest Boundary Containment System (Figure 4.2-21).

Total concentrations in the Basin F plume range from 3.15 ug/l in Wells 23150 and 23118 in Northern Section 23 to 410 ug/l in unconfined Well 26041. There is an area with concentrations below 3.07 ug/l in the north central portion of Section 23, while the highest concentrations occur immediately downgradient of Basin F. The plume generally

occurs in saturated alluvium, but occurs in the unconfined Denver below unsaturated alluvium in northern, eastern and central portions of Section 26 (Figures 4.2-1 and 4.2-21).

A plume also occurs in the First Creek Off-Post pathway. Wells 37373 and 37343, with concentrations of 3.65 and 3.9 ug/l respectively, comprise this plume and are located 1,000 ft apart. This plume is a remnant separated from on-post occurrences by operation of the North Boundary Containment System, and occurs in saturated alluvium. Five wells located outside the Northwest Boundary Containment System occur in the Quincy Street pathway and delineate an apparent arsenic plume occurrence in this area. Concentrations are between 3 to 5 ug/l in this area. Contamination occurs in an area of saturated alluvium.

Several low-level isolated arsenic detections are found in the northern off-post area. These occur between 1,000 and 18,000 ft north of the RMA boundary. Maximum concentration of arsenic in this area is 7.15 ug/l and the lowest detectable concentration is 2.56 ug/l.

4.2.12.3 Denver Aquifer

Arsenic occurs within wells screened in Denver Formation sandstone zones at RMA and detections are listed in Table 4.2-19. Of 138 confined Denver wells analyzed for arsenic, 16 wells contained detectable arsenic. Concentrations range between 2.57 and 26.7 ug/l, with a median concentration of 6.46 ug/l. Based on Third Quarter FY87 analytical results, Arsenic concentrations above the certified reporting limits were detected in samples from wells screened in confined Denver Formation zones A, 1u, 1, 2, 4 and 5. Distributions and concentrations are shown on point plots included in Appendix D.

Eight wells screened in the VCE, A and 1u zones contain detections of arsenic. Unconfined Wells 36056 and 36090, screened in the VC/VCE, and unconfined Well 36139, screened in the A, contained detectable arsenic. In the confined Denver A zone, Wells 36110, 06004, 35066 and 08005, contained detectable arsenic in concentrations of 26.7, 2.57, 12.1 and 2.57 ug/l, respectively. Well 35016 is the only confined Denver well screened in the zone 1u sandstones which had a detectable concentration of arsenic (7.43 ug/l). No alluvial arsenic groundwater source occurs above or near Wells 06004 and 08005. However, the arsenic concentration in these wells is low, and may be associated

with off-post or natural sources. Wells 36110 and 35066 occur in or near Unconfined Flow System groundwater contamination that could influence the Denver Formation detections. Within the zone A wells, correlation may exist between Wells 36110 and 35066, however, these wells are located 5,000 ft apart, making plume association tenuous.

Arsenic was detected in two confined Denver zone 1 wells: Well 26066, with a concentration of 6.76 ug/l, and Well 26086, with a concentration of 6.47 ug/l. Alluvial arsenic contamination occurs near upgradient Well 26086. The only other zone 1 Denver detections are located in unconfined wells, one of which contains 410 ug/l (26041) arsenic.

Confined Denver zone 2 contains three detections of arsenic, in Wells 26061 (5.44 ug/l), 26129 (6.45 ug/l) and 24171 (3.42 ug/l). However, plumes could not be delineated as Well 24171 is located downgradient of the North Boundary Containment System, at least 10,000 ft away from the closest zone 2 detection. Well 24171 occurs near an alluvial arsenic occurrence detected in Well 24163. Wells 26061 and 26129 are located only about 3,000 ft apart in Section 26, but two wells in between them, 26072 and 26067, did not contain detectable levels of arsenic. Well 26129 occurs near zone 1 Well 26086, and could be influenced by zone 1 arsenic contamination if zone interaction occurs in this area.

Of the 24 wells sampled within Denver zone 3, no detections of arsenic were reported. Arsenic detections do occur, however, in the deeper Denver Formation zones. In zone 4, three confined Denver Formation arsenic detections were reported, with concentrations ranging from 4.08 to 8.07 ug/l. These were in Wells 03004, 22023, and 24175, and are spaced so far apart that no plume associations are possible (Appendix D). In zone 5, Wells 04009 and 04011 contain 22.2 and 12.6 ug/l of arsenic, respectively. These wells could define a plume (Appendix D). Arsenic does not occur in Well 04008, nor is it evident in adjacent Well 04009, and a source for these occurrences is not apparent. The other zone 5 detection occurs in Well 22024, with a concentration of 4.94 ug/l. There were no detections of arsenic reported for any of the four wells sampled from wells screened in zones 6 and 7.

4.2.13 Fluoride

Analyses for fluoride (dissolved anion) were performed on 433 groundwater samples collected from alluvial and Denver Formation wells during Third Quarter of FY87.

Fluoride concentrations ranging from 913 to 223,000 ug/l were detected in 291 of the 433 samples analyzed. The distribution of fluoride in the Unconfined Flow System is illustrated on the plume map presented in Figure 4.2-22. Fluoride was detected in confined Denver Formation groundwater within all Denver Formation zones, except VC/VCE. Plume maps for Denver Formation zones A, 1u, 1, 2, 4 and 5 are presented in Figures 4.2-23 through 4.2-28, inclusive. Detections in the remaining Denver Formation zones are shown on the concentration point plots presented in Appendix D. No attempt was made to specifically quantify background concentrations, and all detectable fluoride concentrations were considered during mapping. Fluoride distributions in the Unconfined Flow System and Denver Formation are discussed separately in Sections 4.2.13.2 and 4.2.13.3 below. Alluvial, unconfined Denver Formation and confined Denver Formation fluoride detections are summarized in Table 4.2-5.

4.2.13.1 Historical Water Quality Data

Fluoride is naturally occurring. It was used at RMA in the manufacture of nerve gas (Ebasco, 1988b, RIC#88357R01). During the Initial Screening Program, fluoride was detected in 182 of 294 groundwater samples at concentrations ranging from 1,200 to 306,000 ug/l. Fluoride was detected in 100 of 150 alluvial groundwater samples at concentrations ranging from 1,220 to 306,000 ug/l. Concentrations above 5,000 ug/l were observed in the area of Basin A, north of Basin F and in the vicinity of the North Boundary Containment System. Fluoride concentrations in excess of 1,200 ug/l occurred over a wide area bounded by Sections 1 and 2 on the south; Sections 6, 30 and 31 to the east; and Sections 22 and 27 to the west. Fluoride was detected as far north as the northern boundary of RMA. Most of the highest concentrations of fluoride identified in the alluvial aquifer appeared to be related to sites of known contamination, particularly the South Plants, Basin A and Basin F; however, some relatively high concentrations of fluoride were detected which did not appear to be clearly related to these sites.

Within the Denver Formation, fluoride was observed during the Initial Screening Program at concentrations in excess of 1,200 ug/l over a wide area encompassing most of the western two-thirds of RMA. Concentrations of fluoride in excess of 3,000 ug/l were observed in the vicinity of known source areas including the South Plants, Basins A and C and the Rail Classification Yard. Fluoride was also observed in concentrations exceeding 3,000 ug/l in Sections 3, 4 and 33, but these occurrences did not appear to be

related to known source areas. Isolated occurrences of fluoride were observed in outlying portions of RMA, including Sections 5, 7, 9 and 19.

The distribution of fluoride within the deeper Denver Formation, in wells with screen tops greater than 50 ft below the bedrock contact, was less widespread than the overall Denver Formation distribution. Fluoride was detected extending from south of South Plants to the western RMA boundary and then along the northwest RMA border. Smaller areas of detectable fluoride occurred in the Basin A/Basin A Neck area and along the border of Sections 30 and 31. Isolated occurrences were present in Sections 5, 7, 9, 19, 25, 26 and 29.

Analytical data for fluoride collected during the Initial Screening Program were compared to the USATHAMA historical database and data obtained from the Spaine report (1984, RIC#85133R04). A comparison of the Initial Screening Program data to these historical data confirms general distribution trends of fluoride in the Unconfined Flow System. However, the distributions of fluoride reported in the Initial Screening Program for both the Unconfined Flow System and Denver aquifer are areally more extensive than that observed in the historical data. Many of the isolated occurrences of fluoride observed in the Initial Screening Program in outlying portions of RMA are not confirmed by the historical data.

4.2.13.2 Unconfined Flow System

During Third Quarter FY87, 294 groundwater samples were collected from alluvial and unconfined Denver Formation wells and were analyzed for fluoride. Of these, 259 samples were collected from wells screened within alluvium and 35 samples were collected from wells completed within the Unconfined Flow System in the uppermost Denver Formation. A summary of analytical results for fluoride in alluvial and Denver Formation wells completed within the Unconfined Flow System is presented in Table 4.2-20. The certified reporting limits used for fluoride analyses during the Third Quarter were 1,000, 1,200, and 1220 ug/l. Fluoride concentrations ranging from 1,000 to 223,000 ug/l were observed in 211 of the 295 groundwater samples analyzed.

Table 4.2-20 Summary of Analytical Results for Fluoride for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm

Geologic Unit	No. of Samples Analyzed	No. of Detections	Range of Detection (ug/l) ¹	No. of EDLs*	Range of EDLs (ug/l) ¹
ALLUVIUM	259	179	1,000 - 13,400	2	12,200 - 30,500
DENVER					
B, Unconfined	0	0	--	0	--
B, Confined	2	1	2,020	0	--
VC/VCE, Unconfined	7	7	1,560 - 6,230	0	--
VC/VCE, Confined	0	0	--	0	--
A, Unconfined	3	2	1,670 - 4,190	0	--
A, Confined	28	14	1,180 - 4,830	0	--
1u, Unconfined	0	0	--	0	--
1u, Confined	13	4	1,630 - 5,250	0	--
1, Unconfined	8	8	1,280 - 223,000	0	--
1, Confined	16	10	1,220 - 3,530	0	--
2, Unconfined	13	12	1,200 - 7,500	1	10,000
2, Confined	28	16	1,170 - 3,220	0	--
3, Unconfined	4	3	1,410 - 3,400	0	--
3, Confined	20	11	990 - 3,000	0	--
4, Unconfined	0	0	--	0	--
4, Confined	19	14	913 - 3,190	0	--
5, Confined	9	6	978 - 7,870	0	--
6, Confined	2	2	1,670 - 2,490	0	--
7, Confined	2	2	1,680 - 1,820	0	--

¹ Micrograms per liter
* Elevated detection limit

Source: HLA, 1988.

The distribution of fluoride in the Unconfined Flow System is shown on the plume map presented in Figure 4.2-22. Three fluoride plume areas were identified; the largest plume extending from the South Plants/Lower Lakes area through Basins A to F to beyond the RMA north and northwest boundaries, a second plume extending from west-central Section 35 to the northwest corner of Section 34 and a third plume extending a short distance within Section 2. Isolated detections of fluoride were observed on-post in Sections 4, 6, 7 and 11 and off-post in Sections 16 and 34.

The largest plume area shown in Figure 4.2-22 trends north through the South Plants-Basin A pathways then shifts northwest along the Basin A Neck pathway and continues both north and northwest through the Central and Basin F pathways to the RMA boundary. A plume then occurs off-post, extending approximately 9,000 ft beyond the RMA northwest boundary and approximately 13,000 ft beyond the RMA north boundary. The total plume area extends approximately 32,500 ft in length and ranges in width from 2,000 to 17,000 ft.

A subsidiary component of this plume was identified trending northwest from north-central Section 25 in the North Plants pathway, joining the main body of the plume in northwestern Section 24. Fluoride detections noted in eastern Section 24 may be associated with this plume but may also be related to detections noted in southwestern Section 19 and southern Section 30. The lateral extent of fluoride contamination in the eastern part of RMA cannot be defined.

The trend of this fluoride plume generally follows groundwater flow directions. Furthermore, the lateral extent of concentrations above 1,220 ug/l indicates that effect of hydrodynamic dispersion are more pronounced for fluoride than for many organic compounds. This is a reflection of the relatively nonsorbing character of fluoride. The widespread distribution of fluoride also is a reflection of the large mass of fluoride introduced to the groundwater system.

Fluoride concentrations within this large plume area range from 1,250 ug/l (Well 37349) located off-post in west-central Section 11 to 223,000 ug/l (Well 26041) located adjacent to the north side of Basin F. In general, the highest concentrations of fluoride were observed near sites of known contamination, particularly Basins A and F. Concentrations in excess of 5,000 ug/l were observed in Basin A and downgradient of Basin F. The

highest detection observed off-post was 4,230 ug/l in Well 37339 located adjacent to the RMA boundary in south-central Section 14. Two very high elevated reporting limits were noted downgradient of Basin F in Wells 23049 and 26133, with reporting limits of 12,200 and 30,500 ug/l, respectively. Based on historical data, these two wells were included within the high concentration areas of the plume shown downgradient of Basin F in Figure 4.2-22.

The activated carbon treatment systems at the North Boundary Containment System and Northwest Boundary Containment System are not designed to remove inorganic ions. Fluoride is of particular concern at the North Boundary Containment System because of the current Maximum Contaminant Level (MCL) of 4000 ug/l. The concentrations of fluoride in the North Boundary Containment System plant influent are passing through the plant almost completely unaffected and are observed at similar concentrations in the effluent. The plant, however, does mix the effluent from each of the three separate absorber streams, and the effluent is a composite of the different influent concentrations. The mean North Boundary Containment System plant effluent concentration was 2230 ug/l, which is below the MCL of 4000 ug/l (ESE, 1988e, RIC#88344R02).

Fluoride concentrations decrease with increased distance from RMA and known source areas. Contaminant trends in and around the North Boundary Containment System and Northwest Boundary Containment System will be discussed further in Task 36 (ESE, 1988e, RIC#88344R02), Task 25 (ESE, 1988f, RIC#89024R02) and Task 39 (ESE, 1989b, RIC#89024R01).

The possible sources for fluoride contamination noted within the main body of this plume included the South Plants area and Basins A through F. The North Plants may also be a possible source area for fluoride, particularly for the contamination detected in north-central Section 25 and south-central Section 24. The eastern branch of this plume, trending north from Section 30 to Section 18 off-post is not associated with any known RMA sources. However, the fluoride concentrations detected within this branch of the plume may be related to possible fluoride contamination within First Creek or to possible fluoride occurrences upgradient of RMA.

A second plume of fluoride shown in Figure 4.2-22 trends northwest from the southwest quadrant of Section 35 to the northwest corner of Section 34 in the Central pathway

area. This plume extends approximately 6,300 ft in length and ranges from 600 to 800 ft in width. Fluoride concentrations within the plume range from 1,340 to 1,750 ug/l. The plume primarily occurs within a narrow band of eolian deposits that originate in southern Section 35 and extend to north-central Section 34. The remainder of the plume is within terrace gravels in the western half of Section 34. This plume may be related to fluoride contamination identified in the South Plants.

A third fluoride plume shown in Figure 4.2-22 trends generally west from the southwestern part of the South Plants in Section 2. This plume was observed in an area approximately 3,000 ft in length and ranging from 500 to 1,000 ft in width. Fluoride concentrations within the plume range from 1,590 to 1,970 ug/l. The possible fluoride sources for these detections include the South Plants, Lake Ladora, and the Sand Creek Lateral.

The sources for isolated detections noted in Wells 04008 (3,400 ug/l), 07001 (2,650 ug/l) and 11002 (1,350 ug/l) are unknown. These detections may be related to fluoride sources upgradient of RMA.

4.2.13.3 Denver Aquifer

During Third Quarter FY87, 174 groundwater samples were collected from Denver Formation wells and were analyzed for fluoride. Of these, 35 Denver Formation wells were completed within the unconfined groundwater flow system. The analytical results from these 35 wells are summarized on Table 4.2-20. These results were contoured and discussed in conjunction with the alluvial aquifer in the preceding section. The results of fluoride analyses performed on samples collected from the remaining 139 confined Denver Formation wells are also summarized on Table 4.2-20.

Based on Third Quarter FY87 analytical results, fluoride concentrations above certified reporting limits were observed in samples collected from confined Denver Formation wells completed within every zone except the VC/VCE zone (Table 4.2-20). Plumes were constructed based on fluoride concentrations within Denver Formation zones A, 1u, 1, 2, 4 and 5 (Figure 4.2-23 through 4.2-28). Concentration point plots were generated for the remaining Denver Formation zones. The locations of wells completed within each of these

zones and detected fluoride concentrations are shown on the plume maps and point plots presented in Appendix D.

The distribution of fluoride in the B zone is shown in Appendix D. The single fluoride detection observed in the B zone (Well 05001, 2,020 ug/l) may be the result of naturally elevated fluoride concentrations within the Denver Formation in the area. There are no known sources of fluoride contamination within this portion of RMA.

Within the A zone, 14 of the 28 confined Denver Formation samples analyzed for fluoride contained concentrations ranging from 1,180 to 4,830 ug/l. The distribution of fluoride in the A zone is shown on the plume map presented in Figure 4.2-23. Two fluoride plumes were identified; the largest extending from the South Plants in Section 1 to northwestern Section 2, and the second extending the Basin A Neck in Section 35 to the southwest corner of Section 25.

The largest plume within zone A trends west and southwest from the northwest quadrant of Section 1. The plume extends approximately 5,500 ft in length and ranges from 1,000 to 2,800 ft in width. The northeastern portion of the plume was contoured on the basis of historical fluoride data from Task 4 Initial Screening Program, MKE and USATHAMA. These historical data indicated fluoride concentrations above the certified reporting limits in this area. Fluoride concentrations within the plume range from 1,510 to 4,490 ug/l. The highest concentration was observed in Well 02030 (4,490 ug/l) located in the northeast quadrant of Section 2. The South Plants area was a possible source for the fluoride contamination identified within this plume.

The second plume of fluoride shown in Figure 4.2-23, trends northeast of the Basin A Neck in Section 35 to the southwest corner of Section 25. The plume extends approximately 2,600 ft in length and ranges from 450 to 1,000 ft in width. Fluoride concentrations within the plume range from 1,310 to 4,830 ug/l. The highest fluoride concentration was observed in a sample collected from Well 35066 located in the northeast corner of Section 35. The plume is located within the A sand subcrop and was possibly related to contamination within the Unconfined Flow System in this area.

There were five isolated detections of fluoride observed in wells completed within zone A. The locations and concentrations of these detections are shown in Figure 4.2-23. The

fluoride detections in Wells 11004 and 08005 are not associated with known fluoride sources at RMA. The detections noted in Wells 35062, 36110, and 36121 occur within the A zone subcrop and are therefore probably related to fluoride contamination in the overlying Unconfined Flow System.

Within zone 1u, 4 of the 13 samples analyzed for fluoride contained concentrations ranging from 1,630 to 5,250 ug/l. The distribution of fluoride in the 1u zone is shown on the plume map presented in Figure 4.2-24. A single fluoride plume was identified extending from the northwest quadrant of Section 36 in Basin A to north-central Section 35. The plume extends approximately 5,500 ft in length and ranges from 700 to 1,100 ft in width. Fluoride concentrations within the plume range from 1,630 to 5,250 ug/l. The highest concentration within the plume was in a sample collected from Well 36083, located in northwestern Basin A in Section 36. This plume was possibly related to contamination in the overlying Unconfined Flow System.

A single isolated detection of fluoride was observed within zone 1u in Well 02012 (Figure 4.2-24). The source of fluoride within this well is unknown.

Within zone 1, 10 of the 16 confined Denver Formation samples analyzed contained fluoride, with concentrations ranging from 1,220 to 3,530 ug/l. The distribution of fluoride in zone 1 is shown on the plume map presented in Figure 4.2-25. A single fluoride plume was identified trending northwest and extending from the northwest corner of Basin A to the central portion of Section 26. The plume extends approximately 5,700 ft northwest and approximately 4,700 ft north, and ranges from 500 to 3,000 ft in width. Fluoride concentrations within the plume ranged from 1,220 to 3,530 ug/l. The highest concentration was observed in Well 26066, located within a Denver Formation zone 1 sandstone subcrop area in west-central Basin C. Contamination within the plume was possibly related to the contamination identified within overlying Denver Formation zones and the Unconfined Flow System.

Three isolated fluoride detections were observed within zone 1 in Sections 1, 24 and 25. These detections may be related to fluoride contamination in the overlying Unconfined Flow System in these areas.

Within zone 2, 16 of the 28 samples analyzed for fluoride contained concentrations ranging from 1,170 to 3,220 ug/l. The distribution of fluoride in the zone 2 is shown on the plume map presented in Figure 4.2-26. A single plume was identified trending northwest from the northwest side of Lake Mary to the northeast quadrant of Section 3. The plume extends approximately 2,400 ft in length and ranges from 400 to 750 ft in width. Fluoride concentrations within the plume range from 1,740 to 2,640 ug/l. The highest concentration within the plume was observed in Well 02009 located adjacent to the northwest side of Lake Mary. Fluoride concentrations within the plume were possibly related to contamination in overlying zones but the nature of this relationship is unknown.

As shown in Figure 4.2-26, 14 relatively isolated detections of fluoride were observed within zone 2. The highest isolated detection was 3,220 ug/l noted in Well 37387 located within a zone 2 sandstone subcrop in south-central Section 14 off-post. The fluoride contamination in this well was possibly related to fluoride contamination within the overlying Unconfined Flow System in this area. Similarly, isolated detections noted on-post in Sections 23, 24 and 34 occur in wells located either within or near zone 2 subcrop and may also have been associated with contamination in the overlying Unconfined Flow System. The two isolated detections in Section 26 may be related to contamination within the overlying zone 1. The remaining isolated detections in Sections 1, 9, 25 and 30 show no clear relationship to contamination in the overlying zone.

Within zone 3, 11 of the 20 samples analyzed for fluoride contained concentrations ranging from 990 to 3,000 ug/l. The distribution of fluoride in the zone 3 is shown on the point plot Appendix D. Except for the detection noted in Well 34003, all zone 3 fluoride detections occurred in samples collected from wells located either within the zone 3 subcrop pattern or in areas where contamination was identified in the overlying zone 2. The fluoride detection of 2,200 ug/l noted in Well 34003, located in southwestern Section 34 does not appear to be associated with any known fluoride contamination in this area.

Within zone 4, 14 of the 19 samples analyzed for fluoride contained concentrations ranging from 913 to 3,190 ug/l. The distribution of fluoride in zone 4 is shown on the plume map in Figure 4.2-27. Two plumes were identified; the largest extending from the southwest quadrant of Section 26 to the RMA northwest boundary in Section 22, and the

second trending west-northwest in off-post Section 14. Five isolated detections were observed in Sections 3, 23, 24 and 33.

The largest plume identified trends northwest approximately 4,700 ft and ranges from 1,800 to 3,300 ft in width. Within the plume, fluoride concentrations ranged from 1,260 to 1,830 ug/l. The highest concentration was observed in a sample collected from Well 23193, located in the southeast quadrant of Section 23. Fluoride concentration observed in samples within this plume may relate to fluoride contamination observed within the overlying zone 3.

The second plume trends west-northwest extending approximately 3,800 ft in length and ranging from 1,100 to 2,200 ft in width. Fluoride concentrations within the plume ranged from 1,290 to 2,650 ug/l. The highest concentration was observed in Well 37388 located in south-central Section 14 off-post. Fluoride concentrations in samples from this plume were possibly related to fluoride contamination identified within the overlying zone 3.

Within zone 5, 6 of the 9 confined Denver Formation samples analyzed for fluoride contained detectable concentrations that ranged from 978 to 7,870 ug/l. The distribution of fluoride in zone 5 is shown on the plume map in Figure 4.2-28. A single plume of fluoride was identified trending northwest from north-central Section 4 to the northwest corner of Section 4 and continuing a short distance off-post into Section 5. Fluoride concentrations within the plume ranged from 5,640 to 7,870 ug/l. The highest concentration was observed in Well 04011 located in north-central Section 4. The source of the high concentrations observed in this plume are not known. The isolated detections of fluoride noted in Sections 23, 24, 27, and off post in Section 14 may have been associated with fluoride contamination in the overlying zone 4. However, the fluoride concentration detected in the sample from Well 27055 also appears to be unrelated to any known fluoride sources or overlying zones containing fluoride.

Within the confined Denver Formation zone 6, the two samples analyzed for fluoride contained concentrations of 1,670 and 2,490 ug/l. The distribution of fluoride in zone 6 is shown on the point plot, Appendix D. Well 37319 is located in an area in which fluoride concentrations are observed within overlying zones. Well 28026 is located in an area unrelated to any known fluoride sources or overlying zone containing fluoride detections.

Within the confined Denver Formation zone 7, the 2 samples analyzed for fluoride contained concentrations ranging of 1,680 ug/l and 1,820 ug/l. The distribution of fluoride in zone 7 is shown on the point plot, Appendix D. Wells 33026 and 33032 are both located in an area unrelated to any known fluoride sources or overlying zones containing fluoride detections.

4.2.14 Chloride

Analyses for chloride (dissolved anion) were performed on 433 groundwater samples collected from alluvial and Denver Formation wells during Third Quarter FY87. Chloride concentrations ranging from 5,520 to 28,200,000 ug/l were detected in 426 of the 433 samples analyzed. Typical background levels of Chloride in the Unconfined Flow System range from 34,000 to 102,000 ug/l. The distribution of chloride in the Unconfined Flow System is illustrated on the plume map presented in Figure 4.2-29. Chloride was detected in confined Denver Formation groundwater within every zone, except the VC/VCE. These detections are shown on the Denver Formation plume maps constructed for Denver zones A, 1, 2, 3 and 4 are presented in Figures 4.2-30 to 4.2-34. The Unconfined Flow System plume map and Denver Formation plume maps and point plots are discussed in Sections 4.2.14.2 and 4.2.14.3 below. Alluvial, unconfined Denver Formation, and confined Denver Formation chloride detections are summarized in Table 4.2-5. No attempt was made to specifically quantify background chloride concentrations. Drinking water standards established by the EPA indicate that 250,000 ug/l is the maximum allowable concentration. In light of this, 150,000 ug/l was used as the lowest contour interval, to be sure that all potentially anomalous occurrences were considered in plume mapping. Chloride concentration in areas hydraulically upgradient from known and suspected sources of contamination generally are less than 100,000 ug/l.

4.2.14.1 Historical Water Quality Data

Chloride is prevalent in salts and solvents associated with several processes that were conducted at RMA (Ebasco, 1988b, RIC#88357R01). Historically, widespread occurrences of chloride have been detected in both the alluvial aquifer and the Denver Formation at RMA. During the Task 4 Initial Screening Program, chloride was detected in 285 of 294 groundwater samples analyzed with concentrations ranging from 4,890 to 15,900,000 ug/l. The distribution of chloride concentrations in excess of 250,000 ug/l observed in alluvial

groundwater during the Initial Screening Program, extends from the South Plants to the RMA north and northwest boundaries. This distribution implies a relationship between chloride detections and the presence of the primary RMA contaminant source areas, including the South Plants area and Basins A through F. Initial Screening Program data also indicate that chloride was detected in the Denver aquifer at concentrations in excess of 250,000 ug/l in three primary areas; the South Plants, Basins C through F and Sections 22 and 23 near the RMA boundary.

Historical groundwater data collected prior to the Initial Screening Program from 1975 to 1984, show more widespread chloride distributions in both alluvium and the Denver Formation than Initial Screening Program data. The historical extent of chloride based on these data extends further east, west and south than the distribution shown in the Initial Screening Program report. Within the Denver Formation, these data imply a continuous distribution of elevated chloride concentrations extending from the South Plants to the RMA northwest boundary.

4.2.14.2 Unconfined Flow System

During Third Quarter FY87, 294 groundwater samples were collected from alluvial and unconfined Denver Formation wells and were analyzed for chloride. Of these, 259 samples were collected from wells screened within alluvium and 35 samples were collected from wells completed within the unconfined groundwater flow system in the uppermost Denver Formation. Chloride concentrations ranging from 5,730 to 28,200,000 ug/l were observed in all 294 groundwater samples analyzed. Concentrations in excess of 1,000,000 ug/l were observed within an area extending from Basin A through Basins B, C, D and F to the North Boundary Containment System. Single detections greater than 1,000,000 ug/l were noted in central Section 27 and off-post in southern Section 14, immediately downgradient of the RMA north boundary.

A summary of analytical results for chloride in alluvial and Denver Formation wells completed within the Unconfined Flow System is presented in Table 4.2-21. As shown, chloride was detected in all samples collected from wells within unconfined Denver Formation zones VC/VCE, A, 1, 2 and 3. The highest chloride concentration in

Table 4.2-21 Summary of Analytical Results for Chloride for Wells in the Alluvium, Unconfined Denver Fm and Confined Denver Fm

Geologic Unit	No. of Samples Analyzed	No. of Detections	Range of Detection (ug/l) ¹	No. of EDLs*	Range of EDLs (ug/l) ¹
ALLUVIUM	259	259	25,700 - 6,230,000	0	--
DENVER					
B, Unconfined	0	0	--	0	--
B, Confined	2	2	32,800 - 185,000	0	--
VC, Unconfined	7	7	28,000 - 640,000	0	--
VC, Confined	0	0	19,300	0	--
A, Unconfined	3	3	111,000 - 4,410,000	0	--
A, Confined	28	28	5,520 - 7,290,000	0	--
1u, Unconfined	0	0	14,300 - 1,610,000	0	--
1u, Confined	13	12	50,900 - 28,200,000	0	--
1, Unconfined	8	8	16,600 - 3,200,000	0	--
1, Confined	16	16	16,600 - 3,200,000	0	--
2, Unconfined	13	13	71,400 - 4,750,000	0	--
2, Confined	28	28	5,300 - 1,560,000	0	--
3, Unconfined	4	4	5,730 - 467,000	0	--
3, Confined	20	20	5,600 - 418,000	0	--
4, Unconfined	0	0	--	0	--
4, Confined	19	18	9,540 - 643,000	0	--
5, Confined	9	6	14,600 - 586,000	0	--
6, Confined	2	1	6,110	0	--
7, Confined	2	1	112,000	0	--

¹ Micrograms per liter
* Elevated detection limit

Source: HLA, 1988.

unconfined Denver Formation groundwater was noted in Well 26041 which is located adjacent to Basin F in northeastern Section 26 and screened within 1 ft of the bedrock contact.

The distribution of chloride in the Unconfined Flow System is shown on the plume map presented in Figure 4.2-29. The certified reporting limit used during analyses of Third Quarter FY87 groundwater samples was 4,800 ug/l; however, the lowest contour interval used for plotting chloride concentrations was 150,000 ug/l. This value was selected based on the average chloride concentrations observed in upgradient wells along the southern RMA boundary. Therefore, it is considered to be representative of groundwater influenced by RMA activities, and higher than any potential background concentrations. The average chloride concentration in upgradient RMA wells is approximately 70,000 ug/l. A secondary federal water quality standard for chloride is 250,000 ug/l.

As shown in Figure 4.2-29, five separate chloride plume areas were identified based on Third Quarter FY87 data, and in some areas, on historical water quality data. The largest plume area identified extends from the South Plants/Lower Lakes area through Basins A through F to the RMA north and northwest boundaries. Off-post, an extended plume is present both north and northwest of RMA. As indicated in Figure 4.2-29, the southern extent of this plume has largely been interpreted from historical data. In addition to this major plume, four smaller plumes were also identified; the first trending northwest from the South Plants and extending to southern Section 27; a second trending generally north from northeastern Section 25 through Sections 19 and 24 on-post and Sections 13 and 18 off-post; a third trending west from western Section 2 into eastern Section 3; and a fourth trending north-northwest from southwest Section 4 to west-central Section 4.

The largest plume area shown in Figure 4.2-29 appears to originate in the South Plants/Basin A area. The main body of this plume trends northwest from Basin A through the Basin A/Basin A Neck pathways and then spreads laterally to the north and northwest through the Central and Basin F pathways. Historical data in the South Plants imply that the plume also extends a short distance southwest into Section 2.

From Basin A neck, the plume extends approximately 12,000 ft to the RMA north boundary and approximately 11,000 ft to the RMA northwest boundary. A plume also extends

approximately 10,000 ft beyond both the north and northwest boundaries including the First Creek Off-Post and Northern Off-Post pathways. From the South Plants, the plume extends approximately 4,000 ft to south-central Section 2. The width of the plume on-post ranges from approximately 1,000 ft in the Basin A Neck to 10,000 ft across Sections 22, 23 and 24. The plume appears to be narrower in the off-post areas, ranging from about 2,500 ft across the northwestern extension to nearly 7,000 ft across the northern extension.

Chloride concentrations within the plume range from 155,000 to 28,200,000 ug/l. As discussed previously the highest concentration noted occurred in Well 26041, which is screened within the unconfined portion of the Denver Formation. The highest concentrations noted within the plume tend to occur in the vicinity of possible source areas such as Basins A and Basin F. Furthermore, chloride concentrations within the plume are generally lower in off-post areas than those noted on-post. In both off-post areas, concentrations are generally less than 500,000 ug/l; however, concentrations greater than 500,000 ug/l were noted within the off-post First Creek pathway in Section 14 and Off-Post Northern pathway in Section 12. The highest concentration observed off-post was 2,020,000 ug/l noted in Well 37339, located immediately downgradient to the RMA northern boundary in Section 14.

The trend of this chloride plume generally follows groundwater flow directions. The lateral extent of concentrations above 150,000 ug/l indicates that effects of hydrodynamic dispersion are more pronounced for chloride than for many organic compounds. This is an reflection of the relatively nonsorbing character of chloride. The widespread distribution of chloride also reflects the large mass of contaminant introduced to the groundwater system.

The activated carbon treatment systems at the North Boundary Containment System and Northwest Boundary Containment System are not designed to remove inorganic ions. The concentrations of chloride in the North Boundary Containment System plant influent are passing through the plant almost completely unaffected and are observed at similar concentrations in the effluent. The plant, however, does mix the effluent from each of the three separate absorber streams, and the effluent is a composite of the different influent concentrations (ESE, 1988e, RIC#88344R02). As shown in Figure 4.2-29, the plume continues to the north and northwest past the RMA boundaries. However, the dimensions

of the northwest extension of the plume was inferred within the limits of available data. Contaminant trends in and around the North Boundary Containment System and Northwest Boundary Containment System will be discussed further in Task 36 (ESE, 1988e, RIC#88344R02), Task 25 (ESE, 1988f, RIC#89024R02) and Task 39 (ESE, 1989b, RIC#89024R01).

The plume extends north and northwest from the North Boundary Containment System with separate branches showing preferential contaminant occurrence in the Northern Off-Post pathway and Off-Post First Creek pathway. The northern branch extends approximately 9,000 ft north of the RMA boundary into Section 12 off-post. The northwest arm extends approximately 10,000 ft from the RMA boundary into Section 10 off-post.

There are many potential sources which may contribute to this chloride plume area. These source areas may have included the South Plants area, and Basins A through F.

A second chloride plume shown in Figure 4.2-29 trends northwest from the northeast quadrant of Section 2 to south-central Section 27 in the Central pathway area (Figure 4.2-1). In terms of length, lateral extent and reported concentrations, this plume is much smaller than the plume previously described. This smaller plume measures approximately 11,000 ft in length and ranges from 700 to 3,000 ft in width. Chloride concentrations within the plume range from 151,000 to 750,000 ug/l. The area of the plume outlined in Section 2 is based on historical data including the presence of a chlorine processing plant previously located in the northeast corner of Section 2. The northwest trend of the plume is largely contained within a shallow paleochannel originating in south-central Section 35 and extending to north-central Section 34. The northwestern portion of the plume occurs within terrace gravel deposits in northern Section 34 and south-central Section 27. The highest concentration reported within the plume was 750,000 ug/l in Well 35052 located in southern Section 35. Well 35052 is located directly downgradient of the chlorine processing plant which may have been a source for this plume.

A third plume of chloride is shown in Figure 4.2-29 trending north and northwest from the eastern portion of Section 25 through western Section 19 and northeast corner of Section 24 on-post and in Sections 13 and 18 off-post. The plume extends approximately

11,000 ft in length and ranges from about 600 to 2,000 ft in width. The concentrations reported within this plume are much lower than for the two plumes discussed previously. Chloride concentrations within the plume range from 162,000 to 293,000 ug/l. The highest concentration observed within the plume was in Well 24107, located in the northeast corner of Section 24. The source for chloride identified within this plume may have included the North Plants; however, the majority of the plume does not appear to be associated with any other known RMA source areas.

The fourth plume of chloride shown in Figure 4.2-29 trends generally west from the northwest corner of Section 2 into the northeast quadrant of Section 3. This plume measures approximately 2,300 ft in length and approximately 1,100 ft in width. Chloride concentrations within the plume range from 184,000 to 405,000 ug/l. The source of this plume is not known but may have been related in part to the Sand Creek Lateral.

The fifth plume of chloride shown in Figure 4.2-29 trends north-northwest from the southwest quadrant of Section 4 to west-central Section 4. The plume extends approximately 3,300 ft in length and 700 ft in width. Chloride concentrations within the plume range from 153,000 to 185,000 ug/l. The highest concentration noted within the plume was in Well 04042, located in the southwest quadrant of Section 4. This plume does not appear to be related to any known RMA source area, but may have been associated with possible off-post contamination to the south and west of the RMA.

4.2.14.3 Denver Aquifer

During Third Quarter FY87, 174 groundwater samples were collected from Denver Formation wells and were analyzed for chloride. Of these, 35 Denver Formation wells were completed within the Unconfined Flow System. The analytical results from these 35 wells are summarized on Table 4.2-21. These results were contoured and discussed in conjunction with the alluvial unconfined aquifer in the preceding section. The results of chloride analyses performed on samples collected from the remaining 139 confined Denver Formation wells are also summarized on Table 4.2-21.

Based on Third Quarter FY87 analytical results, chloride concentrations exceeding upper certified reporting limits were observed in samples collected from confined Denver Formation wells completed in every zone except the VC VCE (Table 4.2-21). Plume maps

were constructed based on chloride concentrations within Denver Formation zones A, 1, 2, 3 and 4. Concentration point plots were generated for the remaining Denver Formation zones. The locations of wells completed within each of these zones and detected chloride concentrations are shown on the plume maps and point plots presented in Figures 4.2-30 to 4.2-34 and Appendix D.

Chloride was detected in both wells sampled within Denver Formation zone B (Appendix D). The chloride concentrations noted in these wells were 32,800 ug/l (Well 12003) and 158,000 ug/l (Well 05001). The chloride concentration in Well 05001 appears high compared to the average upgradient concentration of 70,000 ug/l in the Unconfined Flow System and may be a result of upgradient off-post activity.

As shown in Table 4.2-21, all 28 wells within Denver Formation zone A contained detectable concentrations of chloride. Chloride concentrations were observed ranging from 5,510 (Well 11004) to 7,290,000 ug/l (Well 02030). Twenty-one of the samples analyzed contained chloride at concentrations below 150,000 ug/l.

The distribution of chloride in zone A is shown in Figure 4.2-30. A single chloride plume was identified radiating outward from the northeast quadrant of Section 2. The plume is approximately 3,700 ft in length and 2,100 ft in width. Chloride concentrations within the plume range from 245,000 to 7,290,000 ug/l. The highest concentration within the plume was observed in Well 02030 which is located adjacent to a chlorine processing building. Contamination appears to extend to the north, south and west from the vicinity of Well 02030.

Chloride concentration in the Unconfined Flow System beneath the chlorine processing building were substantially higher during the late 1950s than observed in recent years (Konikow, 1977, p. 26). Contamination of Denver Formation zone A probably occurred by vertical migration during that time period. Because hydraulic conductivity and groundwater velocity in the Unconfined Flow System is much larger than in Denver Formation zone A, chloride in the shallow unit has migrated and dispersed while chloride in Denver Formation zone A has remained close to the source of contamination.

Four isolated detections of chloride with concentrations above 150,000 ug/l were also observed within the zone A. These detections occurred in Wells 02021, 35065, 36121 and

36122. Although sources for these isolated detections are not known, these detections may be related to chloride contamination within the overlying Unconfined Flow System.

Within zone 1u, 13 confined Denver Formation samples were collected and analyzed for chloride with resulting concentrations ranging from 14,300 to 1,610,000 ug/l (Table 4.2-21). Ten of the 12 samples in which chloride was detected contained concentrations below 150,000 ug/l. The two isolated detections of chloride within the 1u zone above 150,000 ug/l were observed in Wells 35016 (1,160,000 ug/l), located in the Basin A Neck area and 36083 (226,000 ug/l), located in Basin A. The sources of the chloride concentrations in these wells is probably related to chloride identified within the Unconfined Flow System in this area.

Within zone 1, 16 confined Denver Formation samples were collected and analyzed for chloride with chloride concentrations ranging from 16,600 (Well 01043) to 3,200,000 ug/l (Well 26066). Eleven of the 16 samples contained chloride at concentrations below 150,000 ug/l. As shown in Figure 4.2-31, a single chloride plume was identified trending from the Basin A Neck northwest to Basin C and then north toward Basin F. The plume is approximately 6,000 ft in length and ranging from 500 to 3,000 ft in width. The chloride concentrations within this plume range from 189,000 to 3,200,000 ug/l. The highest concentration was detected in Well 26066 located on the west side of Basin C. The chloride concentrations noted within this plume may be related to chloride contamination in the overlying Unconfined Flow System.

Within zone 2, 28 samples were collected and analyzed for chloride with concentrations ranging from 5,300 (Well 02009) to 1,560,000 ug/l (Well 26061) (Table 4.2-21). Twenty of the 28 samples analyzed contained chloride at concentrations below 150,000 ug/l. As shown on the plume map in Figure 4.2-32, a single chloride plume was identified trending north and west from Basin C, toward Basin F and Basin E in Section 26. The plume is approximately 4,200 ft in length and ranges from 900 to 1,600 ft wide. The chloride concentrations within this plume ranged from 166,000 to 1,560,000 ug/l. The highest concentration within the plume was detected in Well 26061 located in Basin E. Chloride concentrations higher than 150,000 ug/l were observed in five other wells in zone 2: Wells 23186, 25021, 26129, 34006, and 37387. All of these high concentrations except for that noted in Well 25021, may be associated with relatively higher chloride concentrations in the overlying Unconfined Flow System. There is no clear relationship between the

chloride distribution in overlying Unconfined Flow System and elevated chloride concentrations in Well 25021.

Within zone 3, 20 confined Denver Formation wells were analyzed for chloride with concentrations ranging from 5,600 to 418,000 ug/l (Table 4.2-21). Fourteen of the 20 samples analyzed contained chloride at concentrations below 150,000 ug/l. As shown on the plume map in Figure 4.2-33, a single chloride plume was identified trending northwest from the northwest corner of Section 26 to east-central Section 22. The plume is approximately 4,300 ft in length and ranges from 1,500 to 2,300 ft in width. Chloride concentrations within the plume ranged from 214,000 to 346,000 ug/l. Isolated chloride detections were noted within zone 3 in Well 24120, located in the northeast corner of Section 24 and in Well 37379, located in the southwest corner of Section 14 off-post. Sources for the chloride concentrations noted within zone 3 are uncertain.

In the 19 confined Denver Formation zone 4 wells that were sampled, 18 exhibited detectable chloride with concentrations ranging from 9,450 (Well 33016) to 643,000 ug/l (Well 22028) (Table 4.2-21). Twelve of the 18 detections were at chloride concentrations below 150,000 ug/l. As shown on the plume map presented in Figure 4.2-34, two plumes of chloride were identified; the first occurring in eastern Section 23 and western Section 22, and the second trending west-northwest in the southeast quadrant in Section 14 off-post.

The first plume extends approximately 400 ft in length and ranges from 1,000 to 3,800 ft in width. Chloride concentrations within this plume range from 398,000 to 643,000 ug/l. The highest concentration was observed in Well 22028, located in east-central Section 22. This chloride plume may have been related to the chloride plume identified within the overlying zone 3 in this area.

The second plume extends approximately 2,400 ft in length and ranges from 1,000 to 1,400 ft in width. Chloride concentrations within the second plume ranged from 403,000 to 412,000 ug/l. The highest concentration observed within the plume was in Well 37380 located in the southwest corner of Section 14. The source for chloride within this plume is uncertain.

Within Denver Formation zone 5, 6 of the 9 samples collected contained detectable chloride, with concentrations ranging from 14,600 (Well 22024) to 586,000 ug/l (Well 23184). As shown in Appendix D, chloride concentrations in three of the six samples were below the method detection level of 4,800 ug/l. Within zone 5, Wells 22031 and 23184 were the only wells in which chloride concentrations above 150,000 ug/l were noted. The concentrations in these wells may be related to the high chloride concentrations detected in the overlying zone 4 in this area.

Within zone 6 and zone 7, four groundwater samples were collected (two from each zone) and analyzed for chloride. One sample from each zone contained chloride at a concentration above the certified reporting limit. These detections are shown on the point plots presented in Appendix D. A chloride concentration of 6110 ug/l was observed within the zone 6 in Well 37319. Within zone 7, chloride was detected at a concentration of 112,000 ug/l in Well 33016. Sources of these chloride detections are unclear.

4.3 Gas Chromatography/Mass Spectrometry Results

Gas Chromatography/Mass Spectrometry (GC/MS) analyses were performed on groundwater samples collected from selected on-post and off-post wells. The primary objectives of these GC/MS analyses were to:

- o Confirm the occurrence of target analytes previously and concurrently identified by GC analytical methods; and
- o Tentatively identify nontarget analytes to assess possible modifications to the target analyte list.

Additionally, the chemical concentrations reported for the GC/MS analyses were compared to the GC results to assess any systematic differences in the data from the two methods.

The remaining portions of this discussion have been divided into several sections. Well selection procedures are described in Section 4.3.1. Section 4.3.2 describes the GC/MS analytical procedures used and discusses the certified reporting limits. Section 4.3.3 briefly describes Quality Assurance/Quality Control (QA/QC) procedures and discusses the analytical results for external QA/QC samples. The confirmation of target analytes and

their concentrations are described in Section 4.3.4. The identification of nontarget analytes is presented in Section 4.3.5. Section 4.3.6 presents the Conclusions.

4.3.1 Well Selection

Wells were selected for GC/MS analyses based on the well's historical chemical data and location. Initially, wells with historically high concentrations of multiple target analytes were chosen because they provided the greatest opportunity for GC/MS confirmation of target analyte results and the tentative identification of nontarget analytes. In the subsequent sampling rounds, the well's location was also considered in an effort to cover a wide geographic area.

The GC/MS analyses were performed on groundwater samples collected from 131 wells sampled during the Third and Fourth Quarters of Task 4 FY86; and Task 44 Third Quarter FY87. The locations of all wells from which samples were collected for GC/MS analyses are shown in Figure 4.3-1.

Samples were collected from 111 on-post wells and 20 off-post wells, representing approximately 10 percent of the wells sampled during those three quarterly rounds. Ten of these wells were sampled in two quarterly rounds; nine of the wells were sampled in both the Third and Fourth Quarters of Task 4 and one well was sampled in both the Third Quarter of Task 4 and in Task 44. The on-post wells include 77 installed in the Unconfined Flow System and 34 wells completed in the Denver aquifer. All off-post wells are completed in the Unconfined Flow System. Table 4.3-1 lists the wells sampled, aquifer designation and the quarterly round in which samples were collected.

4.3.2 GC/MS Analytical Methods

USATHAMA certified Methods M-8 (for volatiles) and BB-8 (for semivolatile organics) were used for the GC/MS analyses. These methods were derived from EPA methods 624 and 625 respectively. Samples analyzed for volatile organics were processed by standard purge and trap techniques. analyses for semivolatile organics was limited to base/neutral extractables as no acidic extractions of the water samples were performed. The omission

Table 4.3-1 List of Wells from which Water Samples were Collected and Submitted for GC/MS Analysis
(Page 1 of 4)

Well	Aquifer Designation *	Task 4		Task 44
		FY86 3rd Quarter	FY86 4th Quarter	FY87 3rd Quarter
01008	U			X
01012	U	X		
01014	D	X		
01020	U	X		
01021	U		X	
01023	D		X	
02008	U			X
02019	D	X		
02020	U		X	
02030	D	X		
02034	U		X	
02035	D	X	X	
02037	U	X		
02038	D	X		
02039	D	X		
03005	U	X		
03523	U	X		
04007	U	X		
04009	D			X
04014	U		X	
04021	U		X	
04027	U		X	
04030	U	X		
04033	U	X		
06005	D	X		
07001	U	X		
09002	U			X
09005	U	X		
11002	U	X		
22021	U	X		
22024	D	X		
22051	U			X
22059	U		X	
22060	U		X	
23004	U			X
23029	U			X
23095	U		X	
23125	D		X	
23142	U	X		
23177	D	X		

Table 4.3-1 List of Wells from which Water Samples were Collected and Submitted for GC/MS Analysis
(Page 2 of 4)

Well	Aquifer Designation *	Task 4		Task 44
		FY86 3rd Quarter	FY86 4th Quarter	FY87 3rd Quarter
23179	U	X	X	
23182	U		X	
23183	D		X	
23185	U	X		
23188	U	X		
23189	D			X
23190	D	X		
23191**	U		X	
23192**	D		X	
23193	D			X
24092	U			X
24106	U			X
24111	U			X
24113	U			X
24120	D			X
24127	U			X
24150	U	X		
24178	U	X	X	
24185	U		X	
25016	D		X	
25023	D	X		
26011	U		X	
26015	U		X	
26017	U		X	
26020	U		X	
26041	U	X	X	
26066	D	X		
26073	U	X		
26083	U	X		
26084	D	X		
26085	U	X		
26086	D	X		
26127	U	X	X	
26128	D	X		
26133	U	X	X	
26140	D	X		
26142	D		X	
27016	U		X	
27040	U	X		
27049	U			X

Table 4.3-1 List of Wells from which Water Samples were Collected and Submitted for GC/MS Analysis
(Page 3 of 4)

Well	Aquifer Designation *	Task 4		Task 44
		FY86 3rd Quarter	FY86 4th Quarter	FY87 3rd Quarter
27053	U		X	
27055	D			X
27062	U	X		
27074	U			X
28025	U	X		
28027	U	X		
33002	D			X
33024	U		X	
33026	U		X	
33030	U		X	
33034	D		X	
33060	U	X		
33063	U			X
35012	D	X		
35013	U	X		
35016	D			X
35037	U		X	
35038	D		X	
35052	U	X		
35058	U		X	
35063	D		X	
35065	U	X	X	
35066	D			X
36001	U	X		
36065	U		X	
36076	U	X		
36082	U	X	X	
36084	U			X
36090	U			X
36110	D			X
36112	U	X		
36121	D		X	
36139	U			X
37305	U			X
37307	U	X		
37308	U	X		
37309	U			X
37312	U	X		
37313	U		X	
37320	U		X	

Table 4.3-1 List of Wells from which Water Samples were Collected and Submitted for GC/MS Analysis
(Page 4 of 4)

Well	Aquifer Designation *	Task 4		Task 44
		FY86 3rd Quarter	FY86 4th Quarter	FY87 3rd Quarter
37332	U	X		X
37333	U			X
37343	U	X		
37344	U			X
37347	U		X	
37349	U		X	
37353	U	X	X	
37354	U	X		
37356	U		X	
37357	U		X	
37359	U			X
BOLLER	J	X		
CHH	U			X

* U UFS

D Denver

** Only non-target information available for these wells

Source: HLA, 1988.

of acid extractable compounds for Method BB-8 was based upon the analytical parameter list established by the Program Manager. Target analytes for the above mentioned analytical methods are presented on Table 4.3-2.

Appendix D contains all analytical results for groundwater analyses performed by GC/MS. The GC/MS data from the Third and Fourth Quarter FY87 sampling rounds were previously Task 4 presented in the Task 4 Draft Final Report (ESE, 1988a, RIC#88173R06). The GC/MS data from the Task 44 sampling round were not previously reported. The GC/MS target analyte lists were the same for the Task 4 and Task 44 sampling rounds.

Table 4.3-3 lists GC/MS certified reporting limits for the target analytes. GC certified reporting limits for each of the volatile halogenated organics and volatile aromatic organics are similar or equal to the respective GC/MS certified reporting limits. The greatest deviation for this group of compounds is for chlorobenzene, which has a GC certified reporting limit of 0.58 ug/l and a GC/MS certified reporting limit of 2.0 ug/l. The certified reporting limits for the organochlorine pesticides show the greatest differences between the GC and GC/MS methods. The GC certified reporting limits for these compounds range from 0.05 to 0.07 ug/l, whereas the GC/MS certified reporting limits range from 4.7 to 10 ug/l. Thus, the GC certified reporting limits are approximately 100 times lower than the GC/MS certified reporting limits. These wide differences can have an impact on compound quantification, as described in Sections 4.3.3 and 4.3.4.

4.3.3 Quality Assurance/Quality Control

QA/QC procedures for groundwater sampling and laboratory analyses are described in the Final Screening Program, Third and Fourth Quarter Final Report (ESE, 1988a, RIC#88173R06) and the Task 44 Technical Plan (ESE, 1988). External QC samples consisting of trip blanks were submitted to the laboratories for GC/MS analysis of selected volatiles, volatile aromatic organics and pesticides by EPA method 624. The blanks were generally submitted to the laboratories at a frequency of one per day; however, they were not submitted for six of the 48 sampling dates. Additionally, duplicate trip blanks were submitted on three sampling dates. A total of 45 trip blanks were submitted to the laboratories for chemical analysis.

Table 4.3-2 GC/MS Target Analytes

Analytes by EPA Method 624 (USATHAMA Method M-8)

Ethylbenzene (ETHYLBENZ)*
 Benzene (BENZENE)
 Methylisobutyl Ketone (MIBK)
 Dimethyldisulfide (DMDS)
 1,1-Dichloroethane (11DCLE)
 1,2-Dichloroethane (12DCLE)
 1,1,1-Trichloroethane (111TCE)
 1,1,2-Trichloroethane (112TCE)
 Methylene chloride (METHYLCL)
 Chloroform (CHCL3)
 Carbon tetrachloride (CCL4)
 trans-1,2-Dichloroethylene (12DCLE)
 Chlorobenzene (CLC6H5)
 Tetrachloroethylene (TCL4)
 Trichloroethylene (TRC3E)
 meta-Xylene (m-XYL)
 ortho-Xylene (o-XYL)
 para-Xylene (p-XYL)
 Dibromochloropropane (DBCP)
 Dichloropentadiene (DCPD)
 Toluene (TOLUENE)

Analytes by EPA Method 412** (USATHAMA Method BB-8)

Aldrin (ALDRIN)
 Chlorophenylmethylsulfide (CPMS)
 Chlorophenylmethylsulfoxide (CPMSO)
 Chlorophenylmethylsulfone (CPMSO2)
 Dibromochloropropane (DBCP)
 Dichloropentadiene (DCPD)
 p,p'-DDE (p,p'-DDE)
 p,p'-DDT (p,p'-DDT)
 Dieldrin (DIELDRIN)
 Diisopropylmethyl phosphonate (DIMP)
 1,4-Dithiane (1,4-DITH)
 Endrin (ENDRIN)
 Hexachlorocyclopentadiene (HCCPD)
 Isodrin (ISODRIN)
 1,4-Oxathiane (1,4-OXAT)

* compound name abbreviation used in data tables
 ** neutral extraction fraction

Source: HLA, 1988.

Table 4.3-3 Certified Reporting Limits for Target Analytes
(Page 1 of 2)

Analysis/Analytes	GC Certified Reporting Limit (ug/l)	GC/MS* Certified Reporting Limit (ug/l)
<u>Organochlorine Pesticides</u>		
Aldrin	0.07	4.7
Endrin	0.05	7.6
Dieldrin	0.06	4.7
Isodrin	0.06	5.9
He achlorocyclopentadiene	0.07	11
p,p'-1,1-dichloro-2,2-bis(4-chlorophenyl)-ethylene	0.05	4.7
p,p'-dichlorodiphenyltrichloroethane	0.07	10
<u>Volatile Halogenated Organics</u>		
Chlorobenzene	0.58	2.0
Chloroform	1.4	1.0
Carbon Tetrachloride	2.4	2.0
trans-1,2-Dichloroethylene	1.2	2.0
Trichloroethylene (TCE)	1.1	1.0
Tetrachloroethylene	1.3	1.0
1,1 Dichloroethylene	1.1	-
1,1-Dichloroethane	1.2	2.0
1,2-Dichloroethane	0.61	1.0
1,1,1-Trichloroethane	1.7	1.0
1,1,2-Trichloroethane	1.0	1.0
Methylene Chloride	5.0	5.0
<u>Organosulfur Compounds</u>		
Chlorophenylmethyl sulfone (CPMSO ₂)	4.7	8.0
Chlorophenylmethyl sulfoxide (CPMSO)	4.2	17
Chlorophenylmethyl sulfide (CPMS)	1.3	14
1,4-Dithiane	1.1	11
1,4-Oxathiane	2.0	6.1
Dimethyldisulfide (DMDS)	1.8	3.0
<u>Volatile Aromatics</u>		
Toluene	1.2	1.0
Benzene	1.3	1.0
Xylene (meta-)	1.4	1.0
Xylene (ortho-, para-)	2.5	2.0
Ethylbenzene	1.3	1.0

Table 4.3-3 Certified Reporting Limits for Target Analyte
(Page 2 of 2)

Analysis/Analytes	GC Certified Reporting Limit (ug/l)	GC/MS* Certified Reporting Limit (ug/l)
<u>DCPD/MIBK</u>		
Dicyclopentadiene	9.3	2.0; 4.7*
Methylisobutyl Ketone	13	2.0
<u>DIMP/DMMP</u>		
Diisopropylmethyl phosphonate	11	5.7
Dimethylnethyl phosphonate	10.5	Not Certified
<u>DBCP</u>		
Dibromochloropropane	0.13	4.0; 15*

* GC/MS detection limits for EPA Methods 624;625, respectively at ESE Gainesville Laboratory.

Source: HLA, 1988.

Data included in Appendix D show the target analytes and analytical results for the trip blanks. As can be seen, target analytes were generally not found in the trip blanks, although a few target compounds, including 1,1,1-trichloroethane, methylene chloride, chloroform, toluene and meta-xylene, were inconsistently detected. Detectable levels of 1,1,1-trichloroethane, chloroform, and meta-xylene were individually found in three different blank samples. Methylene chloride and toluene were found in eight and two sample blanks. Nine blanks contained methylene chloride ranging from 4.72 to 15.9 ug/l. Toluene was found in four blanks at concentrations from 1.1 to 1.7 ug/l. In general, the concentrations of all compounds detected in the blanks were less than twice the compound's respective certified reporting limits. Most of the blanks found to contain low levels of the target analytes were from the Fourth Quarter of Task 4 sampling round.

The trip blank data indicate low level contamination by a few compounds. However, they do not appear to indicate the existence of a possible contamination problem that might warrant corrective actions. The source of the contamination is not specifically known; however, the low levels of methylene chloride and toluene may be related to laboratory extraction and cleanup procedures.

A number of wells were sampled in more than one sampling round for GC/MS confirmation analyses. Table 4.3-1 shows the wells from which more than one sample was collected and submitted for GC/MS analysis. The data from these replicate analyses were compared to assess the consistency of the results. The data were comparable between sampling events, with similar compounds detected at concentrations differing by generally far less than an order of magnitude. In a few sample replicates concentrations of 1,2-dichloroethane and chlorobenzene were below certified reporting limits by GC, but were detected at relatively high concentrations by GC/MS analytical methods.

4.3.4 Confirmation of Target Analytes and Concentrations

GC/MS methods were used to confirm the identification of target analytes determined by GC methods. The concentrations of the target analytes reported by GC methods were also verified by GC/MS methods. Concentrations were considered confirmed if the GC and GC/MS values were within an order of magnitude. In general, the GC/MS results confirm target analyte identification and concentration reported by GC methods. In some cases

confirmation of analyte identification was not possible because the GC/MS detection limits were higher than the concentration reported by the GC method. This situation was most frequently observed with the semivolatile fraction, particularly the organochlorine pesticides. These had GC/MS certified reporting limits that were up to 100 times higher than the GC certified reporting limits.

The analytical results were fairly consistent between the GC and GC/MS methods, although systematic deviations were noted for some compounds including chloroform, diisopropylmethyl phosphonate, chlorophenylmethyl sulfoxide and chlorophenylmethyl sulfone. Chloroform showed concentrations of 20 to 40 percent higher for the GC/MS method. The results for diisopropylmethyl phosphonate, chlorophenylmethyl sulfoxide and chlorophenylmethyl sulfone showed GC results typically 20 to 50 percent higher than the reported GC/MS value. These systematic relationships were not evaluated statistically because the number of samples in which these compounds were detected were relatively small, and the analytical results were sometimes low in concentration (in the range of 10 to 20 ug/l). The data for other target analytes were also reviewed and possible trends evaluated. Systematic deviations in the concentrations of other target analytes were not noted for the GC and GC/MS methods.

4.3.5 Nontarget Compound Analytical Results

4.3.5.1 Uncertainties in Nontarget Identification

Identification of target analytes can be performed by several different analytical procedures, that contain specific protocols for target compound identification and quantification. For each analytical method, there is a different degree of certainty associated with the identification process. Although the term "identification" is sometimes used without qualifications, a more accurate description of a method's results should involve qualifiers. The term "tentatively identified" is the most common terminology for indicating lower degree of certainty associated with the identification of an organic compound.

According to standard analytical chemistry practice, compound identification requires several different types of confirming analytical evidence. In GC/MS, an unknown is said to be "identified" if its mass spectrum matches the mass spectrum in a library database.

and its mass spectrum and retention time matches those of an authentic standard. Tentative identification usually means that a compound was identified based on a comparison between its mass spectrum and the mass spectrum of a library compound. This library matching process is conducted by a computer program that automatically assigns a compound identification based on a probability factor. These spectra are also examined by an expert mass spectroscopist who confirms the computer matches and assigns other tentative identifications where possible. In this procedure authentic standards are not analyzed so it is not possible to compare retention times and mass spectra, therefore, there exists a much higher degree of uncertainty in the Tentatively Identified Compounds information. It is inappropriate to draw conclusions based on a "single" Tentatively Identified Compound result or set of Tentatively Identified Compound results without the support of confirmed compound identification information.

The Tentatively Identified Compound information can be useful in a general sense but it can also be unreliable and misleading if the data are used without regard for the associated uncertainties. Tentatively Identified Compounds are most useful for determining the course of future sampling/analytical activities and as supportive information to confirmed identified compound results.

4.3.5.2 Nontarget Compound Identification

Appendix D presents the analytical results for nontarget compounds identified by GC/MS analysis. The identification and quantification of these nontarget analytes were performed by contractor personnel. Nontarget compounds in each GC/MS analyses were reported if they met or exceeded a certain criteria based on the abundance of the most intense ion in the internal standard. The approach that has been used to report these unknowns consists of keying them to their relative retention times.

The following two examples demonstrate the method of reporting unknowns. For the first example, assume two unknowns are present in sufficient quantities in a volatiles analysis to satisfy criteria such that they must be reported and that they elute with relative retention times of 0.85 and 2.13 compared to the internal standard 1,2-dibromoethane- D_4 . These two unknowns will be identified as UNK085 and UNK213. Because relative retention times for the volatiles are unable to exceed 50, no values above UNK500 will be encountered. UNK501 through UNK999 are reserved for semivolatiles analysis.

A second example for semivolatiles will demonstrate how they are reported. For this example, assume that three unknowns which elute at relative retention times of 0.51, 1.22 and 3.54 compared to the internal standard phenanthrene D-10, exceed criteria and must be reported. Because values between UNK001 and UNK500 are reserved for unknowns from volatiles analysis, 500 is added to the relative retention time. Thus, these three unknowns would be reported as UNK551, UNK622, and UNK854.

Qualitative concentrations are calculated for the unknowns based on assuming a 1:1 response factor relationship between the abundance of the nontarget compound and the internal standard. This assumption introduces a large degree of uncertainty in the reported concentration.

4.3.5.3 Nontarget Compound Occurrence and Distribution

Numerous non-target compounds were detected using GC/MS. Some of these compounds were tentatively identified (TIC) and assigned chemical names. Nontarget GC/MS data, including the unidentified compounds, appear in Appendix D listed by well number.

A total of 157 Tentatively Identified Compounds were detected in groundwater samples, although only 20 Tentatively Identified Compounds were detected in 10 or more samples. The Tentatively Identified Compounds most commonly found include halogenated and nonhalogenated hydrocarbons and fuel-related compounds.

Approximately 13 of the Tentatively Identified Compounds are target analytes. Because of the methods used to quantify Tentatively Identified Compound concentrations, as previously described, the concentrations of these target analytes are considered only approximate. Excluding those target analytes, at least 12 of the remaining Tentatively Identified Compounds are on the CERCLA Hazardous Substance List (HSL), including 1,1,2,2-tetrachloroethane, bis(2-ethylhexyl)phthalate, hexachlorobutadiene, dichlorobenzene, tetrachlorobenzene, chloromethylphenol, methylnaphthalene, trichlorobenzene, tetrachlorophenol, naphthalene, phenol and pentachlorophenol.

A number of additional Tentatively Identified Compounds reported to be naturally occurring or laboratory artifacts, including octadecanoic acid, octadecanamide,

dodecanoic acid, tetradecanoic acid, decanoic acid, diphenyl ether, hexanone, propanoic acid, 2-propanone (acetone), methyl ester of dihydroxybenzoic acid and bis (2-ethylhexyl)phthalate.

The concentrations of the Tentatively Identified Compounds span a wide range. The highest reported Tentatively Identified Compound concentration was for dichlorobenzene at 153,000 ug/l. A total of 22 samples had concentrations of at least one analyte above 1,000 ug/l and 36 samples had concentrations between 100 ug/l and 1,000 ug/l. The remaining samples had reported concentrations below 100 ug/l. These concentrations are considered approximate because of the method of quantification (Section 4.3.5.3).

The distributions of the 20 most commonly occurring nontarget analytes are shown as figures in Appendix D. These figures depict the combined distribution in the alluvial/unconfined and Denver Formation aquifer systems. These data were composited to facilitate the assessment of possible relationships between the two aquifer systems.

A more specific discussion of non target compounds on the CERCLA Hazardous Substance List follows. A discussion of caprolactum also is presented.

1,1,2,2-Tetrachloroethane

1,1,2,2-tetrachloroethane is widely distributed at RMA. It is present in the Motor Pool and Railyard Pathway, North Central Pathway, and the Basin F Pathway (Figure D-169). Potential sources for each pathway include the motor pool area, South Plants manufacturing complex and the disposal Basins A, B, C, D, E, and F. The distribution of 1,1,2,2-tetrachloroethane is coincident with the distribution of the summed volatile halogenated organic (Figure 3.3, Volume I).

Bis (2-ethylhexyl) phthalate

This compound was detected within the central portions of RMA from South Plants to the RMA north boundary (Figure D-173). This area includes the northern South Plants Pathway, Basin A/Basin A Neck Pathways, Basin F East Pathway, Basin F and Basin F Northwest Pathways. Isolated detections include Well 33026 in the vicinity of the Irondale Containment System, the Boller Well in Section 12 (offpost) and Well 37354 in Section 2 (offpost). Phthalates are ubiquitous plasticizers. Based on their distribution South Plants, Basins A, B, C and F are considered potential sources.

Hexachlorobutadiene

Hexachlorobutadiene was detected in Wells 23095, 23179 and 26133 along the Basin F pathway. The Basin F area is the probable source of this contamination. Well 26133 is the northernmost of the three wells and is located approximately 2000 ft north of Basin F.

Dichlorobenzene

Dichlorobenzene was detected in wells 01020, 36001, 36076 and 37359 (offpost). With the exception of Well 37359, all detections occurred in the South Plants to Basin A Pathway. The probable source is the South Plants manufacturing complex. The distribution of dichlorobenzene is similar to the distribution for other chlorinated benzene and chlorinated phenols in the area just north of the South Plants. Dichlorobenzene was also detected in Well 37359 in Section 29 adjacent to the O'Brian Canal (offpost). The source of this contamination is unknown.

Trichlorobenzene

Trichlorobenzene was detected in Wells 36001 and 36076 both of which are located directly north and downgradient from South Plants along the South Plants to Basin A Pathway. Other related compounds including chlorinated benzenes and chlorinated phenols were also detected in these wells.

Tetrachlorobenzene

Tetrachlorobenzene was detected in the Basin F Pathway in Wells 23004 and 23179. It was also detected in Well 36001 located immediately downgradient of the South Plants. The Basin F area and the South Plants manufacturing complex are the probable source areas for this compound. These detections lie near the centroids of the plumes mapped for volatile aromatic compounds (Figure 4.2-9).

Tetrachlorophenol

Tetrachlorophenol was detected in Well 36076 located north and downgradient of the South Plants. Other related compounds such as chlorinated benzenes and pentachlorophenol were also detected in this well.

Pentachlorophenol

Pentachlorophenol was detected in Well 36076 located north and downgradient of the South Plants. Other related compounds were also detected in this well.

Chloromethylphenol and Phenol

Two compounds listed as "possibly" chloromethylphenol and phenol were detected in Well 26041 located immediately adjacent to the northeast corner of Basin F. Basin F is the probable source of these tentatively identified compounds.

Naphthalene and Methylnaphthalene

Naphthalene and Methylnaphthalene were detected in Well 01014 near the South Tank of the South Plants. These nonchlorinated aromatics are probably related to other aromatic compounds in this area such as the benzene. The South Tank Farm is the probable source for these contaminants. Methylnaphthalene was also detected in Well 04009 located near the western entrance to RMA. This well is screened in the Denver Formation and the source of this contamination is unknown.

Caprolactum

Caprolactum is widely distributed in groundwater at RMA. It is not on the 1988 EPA hazardous substance list, however, it is toxic by inhalation at 5 pp, in air (Sax and Lewis, 1987) and is used in the manufacture of synthetic fibers such as nylon. Caprolactum was detected in the southern South Plants Pathway, South Plants and Basin F Northwest Pathways. It was also detected in the Western Tier and north of RMA along the First Creek Offpost Pathway (Figure D-174). The source of caprolactum is unknown. Caprolactum currently is being considered as an addition to the target compound list for future ground-water monitoring programs.

4.3.6 GC/MS Conclusions

The results of the GC/MS analyses indicate the following:

- o GC results for target analytes, including compound identification and quantification, were generally confirmed by GC/MS analyses;
- o Numerous nontarget analytes are present in groundwater samples collected from many on-post and off-post wells; and

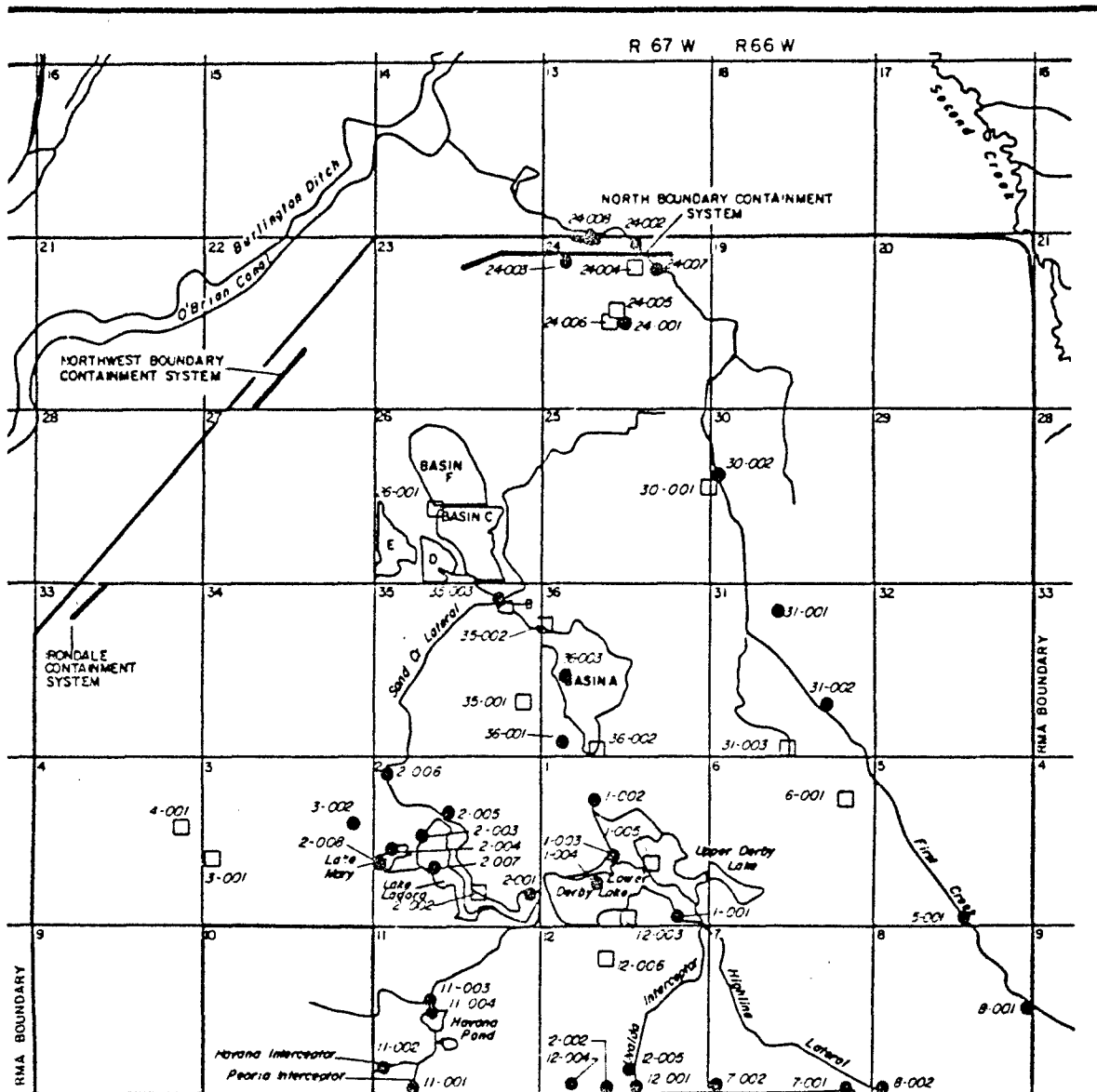
- o The distribution of the 20 most commonly occurring nontarget analytes appears to be similar to the distribution of the target analytes, suggesting similar source areas and migration pathways.

The target compounds historically identified by GC analytes were confirmed in samples analyzed by GC/MS analytical methods. On a number of occasions some compounds could not be confirmed by GC/MS methods because of differences in method detection limits or sometimes as a function of high dilution factors.

The concentrations reported by GC methods also were generally consistent with concentrations attained by the GC/MS methods. Concentrations were considered confirmed if GC and GC/MS results were within an order of magnitude.

The results of the nontarget assessment showed that numerous nontarget analytes exist in the groundwater samples from many areas of RMA where relatively high concentrations of target analytes exist. These nontarget analytes commonly consist of halogenated and nonhalogenated hydrocarbons and fuel-related compounds. The distribution of these compounds is generally within the major plumes of the target analytes.

Although many nontarget compounds were reported, only about 20 were found in 10 or more of the groundwater samples. Most of these 20 analytes were fuel-related compounds or halogenated hydrocarbons and ranged in concentration from less than 10 ug/l to as high as 8,800 ug/l. The nontarget compound detected in the highest concentration was dichlorobenzene at 153,000 ug/l in Well 36076 located in the vicinity of Basin A.



EXPLANATION

- Dry Site
- Sampled Site

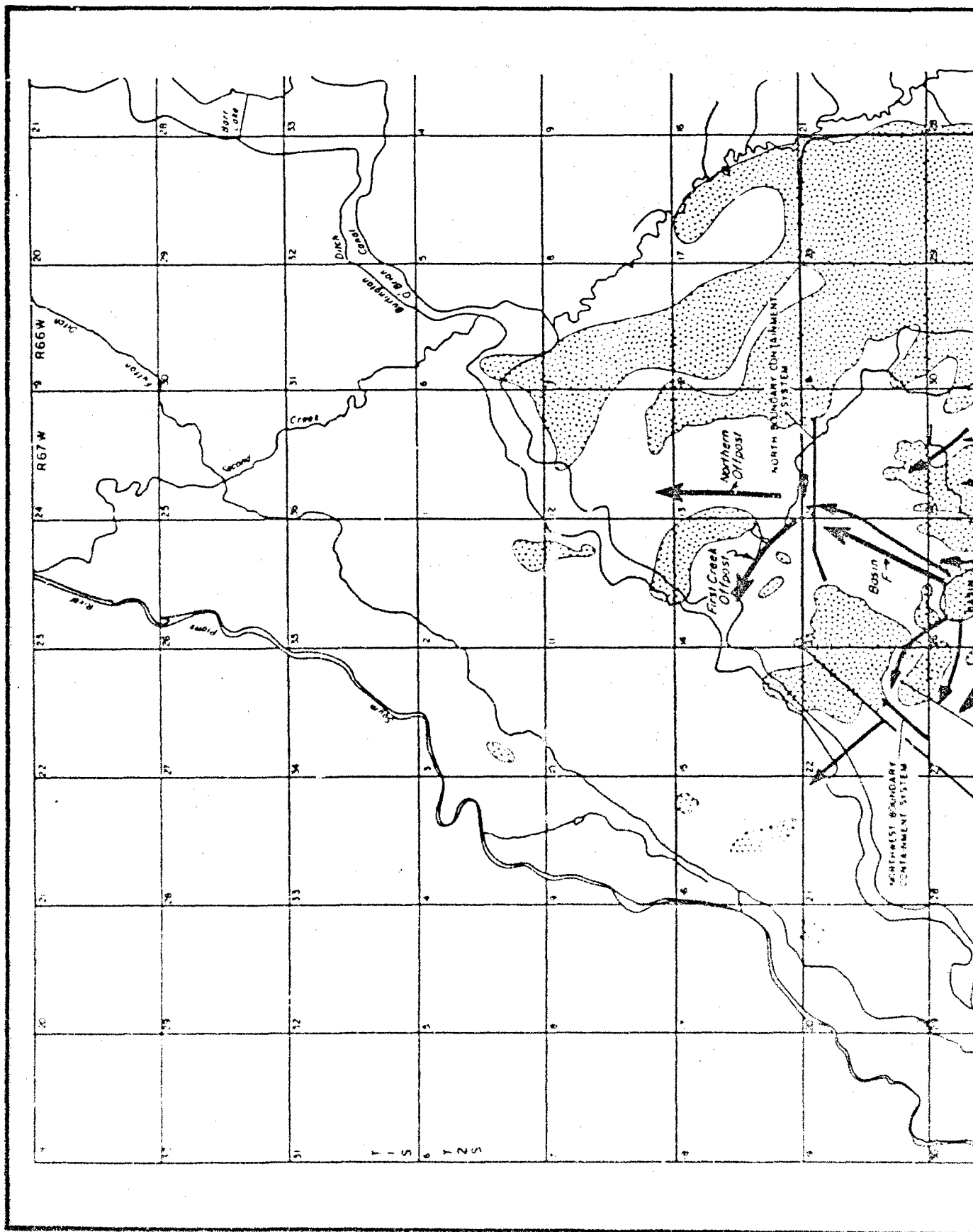


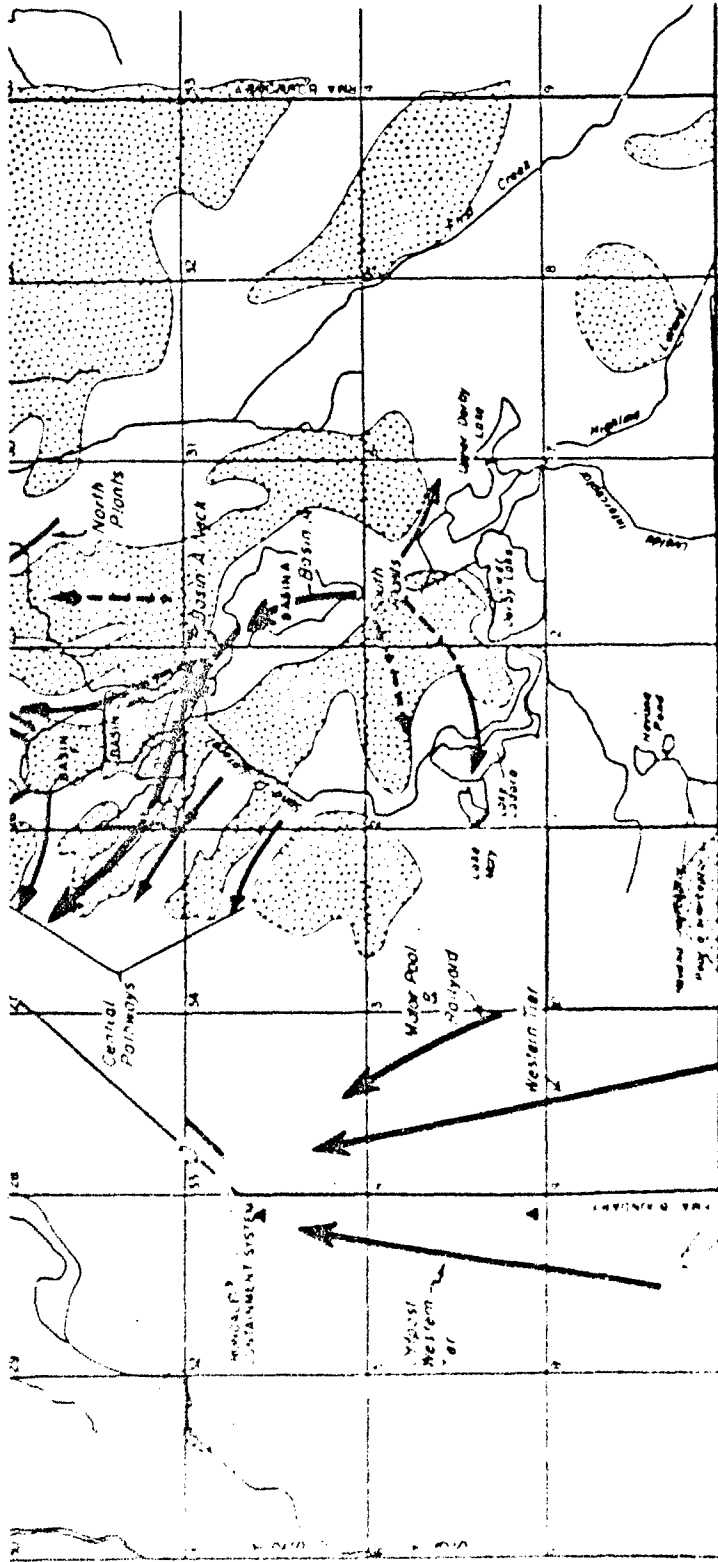
Figure 4.1-1

GROUNDWATER QUALITY
SAMPLING SITES AT RMA

RCE: Hunter/ESE, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland





EXPLANATION

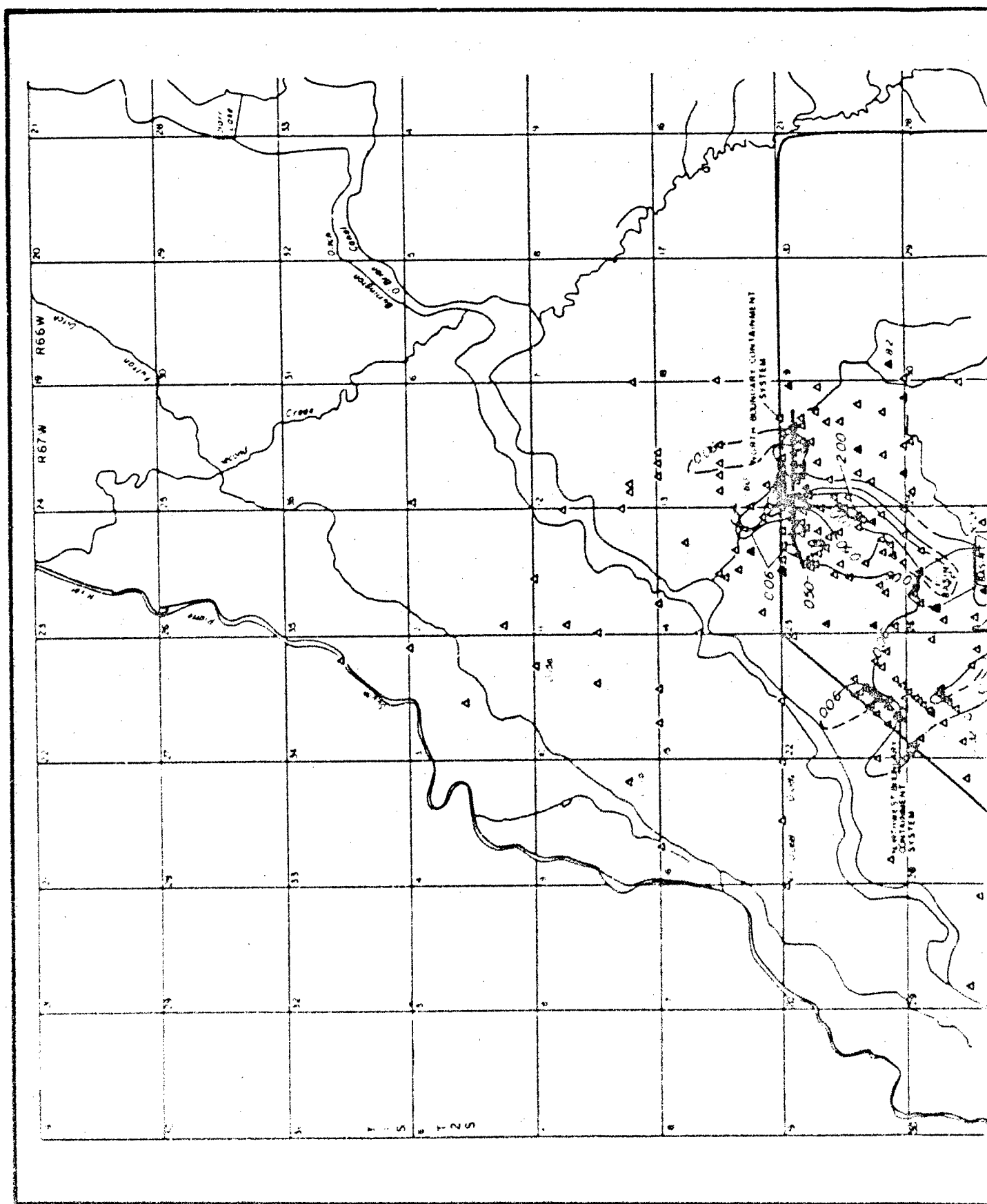
- Primary Pathway Cashed Where Location is Approximate
- Secondary Pathway Cashed Where Location is Approximate
- Unsatuated Aquifer
- South Adams County Water Supply District Well

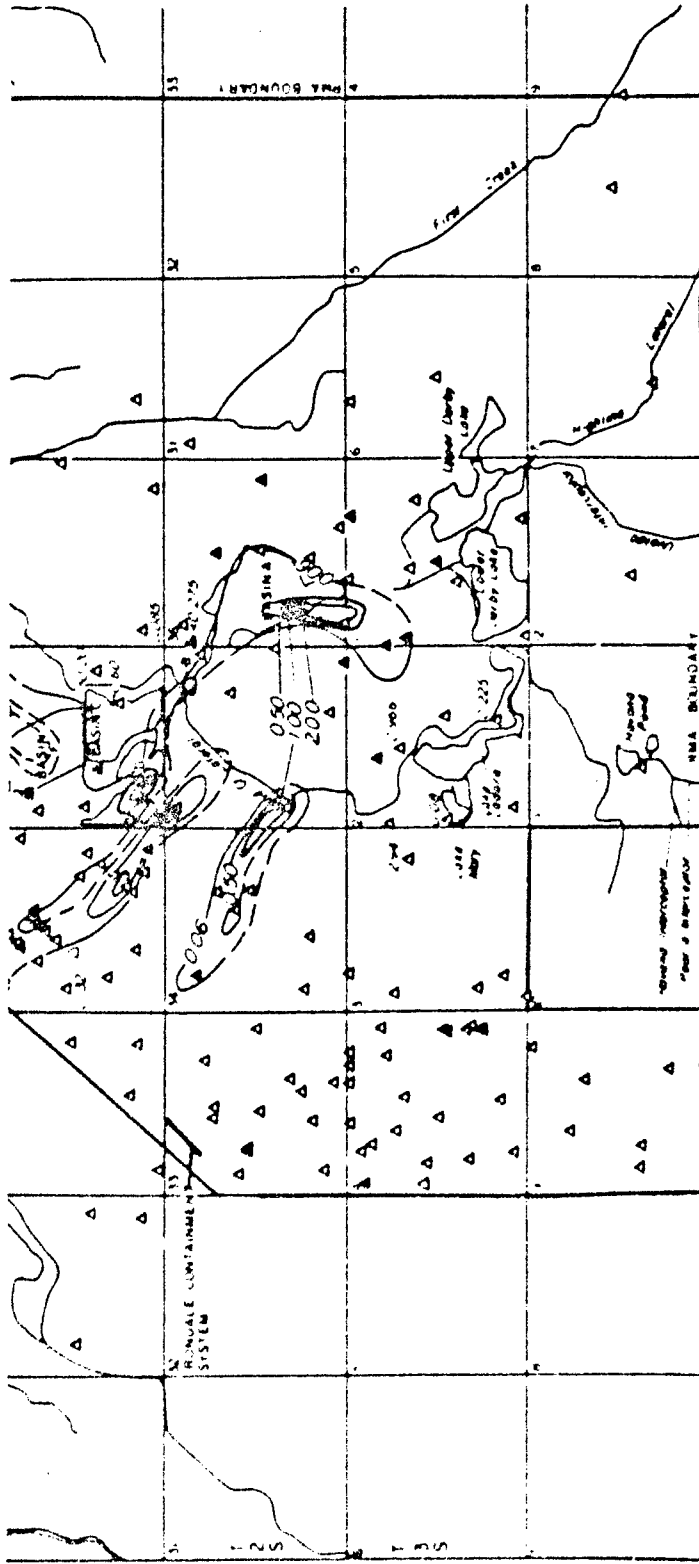
Figure 4 2-1

RMA CONTAMINANT MIGRATION PATHWAYS

SOURCE: HANCOCK, ESE, 1988

Prepared for:
 U.S. Army Program Manager's Office
 For Rocky Mountain Arsenal
 Aberdeen Proving Ground, Maryland





EXPLANATION

- △ Active Well
- △ Unconfined Detector/Isolation Well
- Isolation Line or Detection Less Than Highest CHT, In light
- △ Isolated Detection Or Detection Less Than Highest CHT, In light
- Contour Interval Values

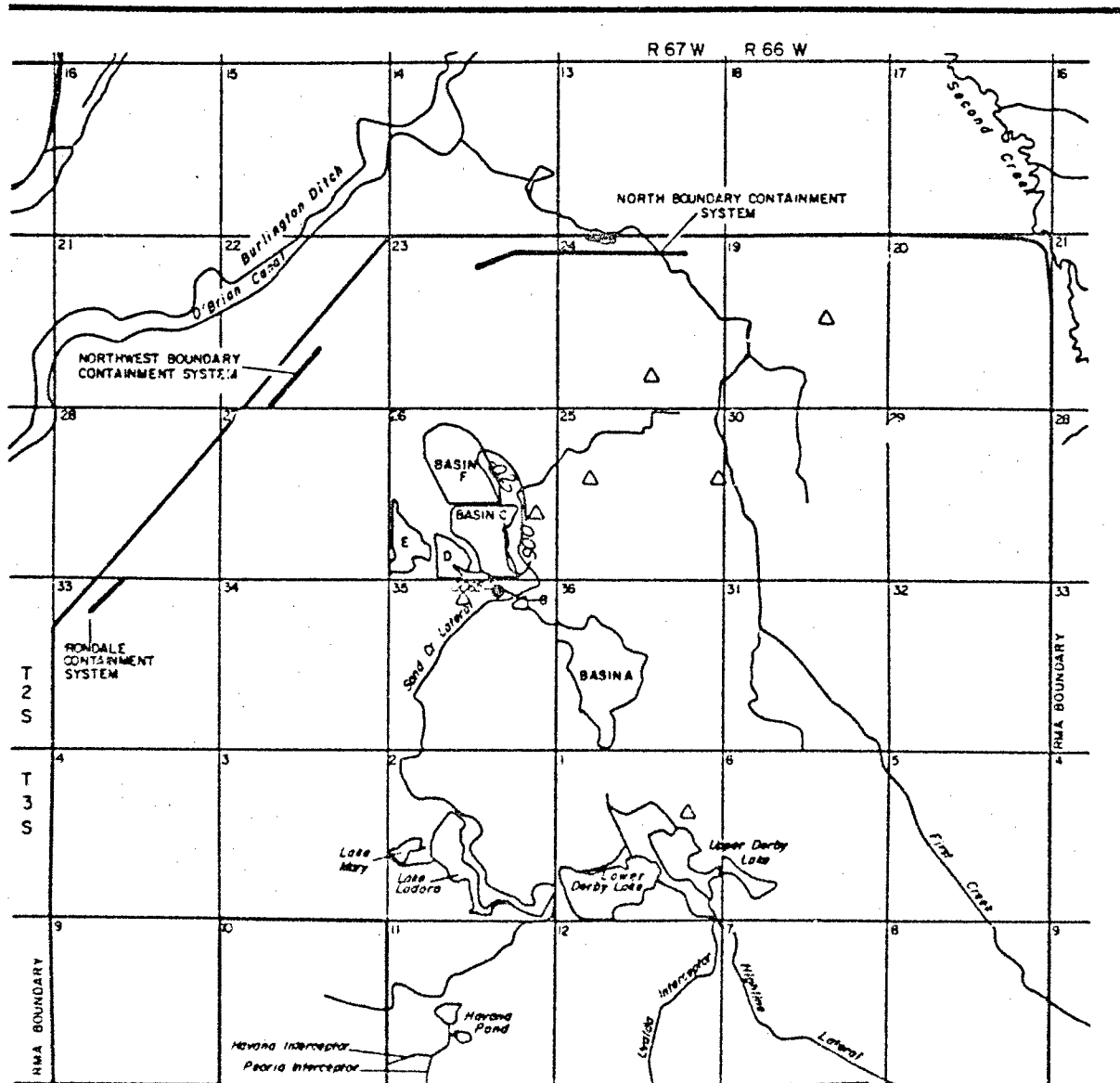
Figure 4.2-2

DIEHRIN PLUMES UNCONFINED GROUNDWATER FLOW SYSTEM
3RD QUARTER FY 1987

SOURCE: HLA 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal

Aberdeen Proving Ground, Maryland



EXPLANATION

- △ Confined Denver Fm. Well
- Equiconcentration Line
Dashed Where Inferred
- Isolated Denver Fm. Detection
Or Detections Less Than
Highest CRL In ug/l
- Contour Interval Varies

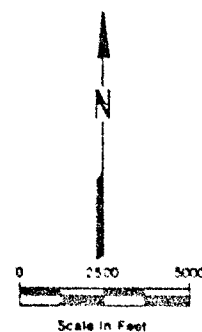
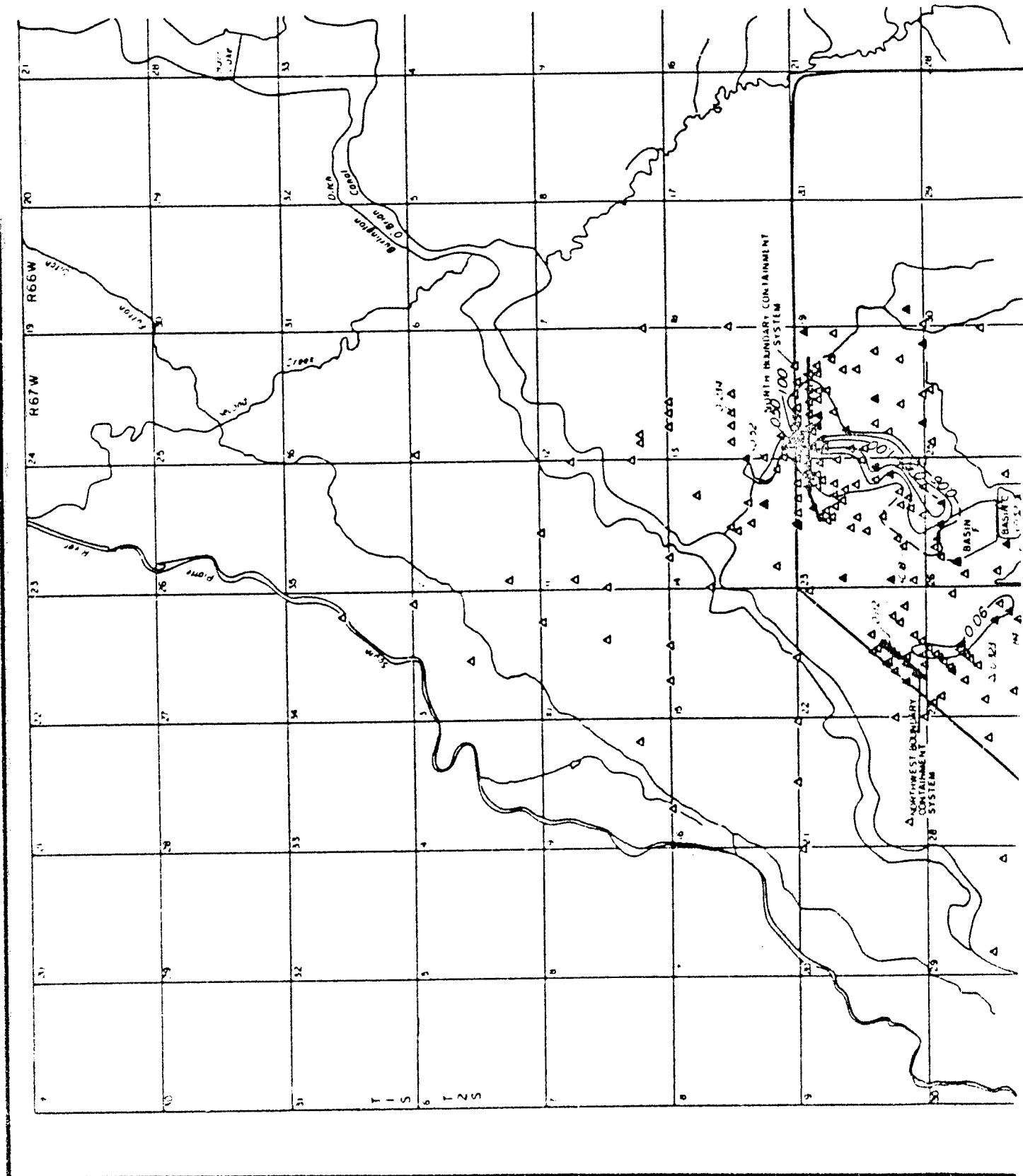


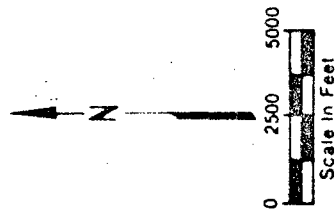
Figure 4.2-3

IELDRIN PLUMES CONFINED DENVER FM.
ONE 1, 3RD QUARTER FY 1987

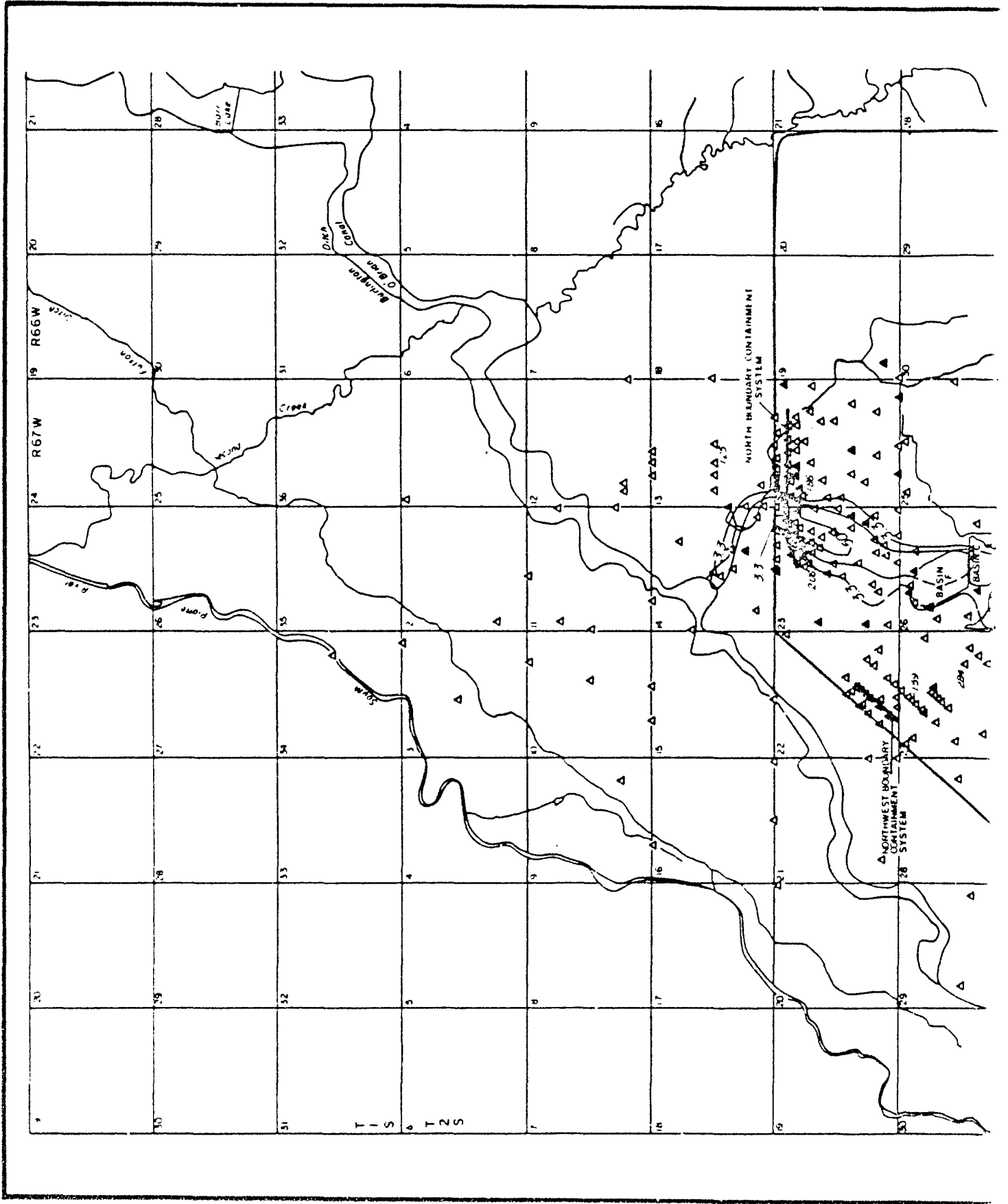
SOURCE: HLA, 1988

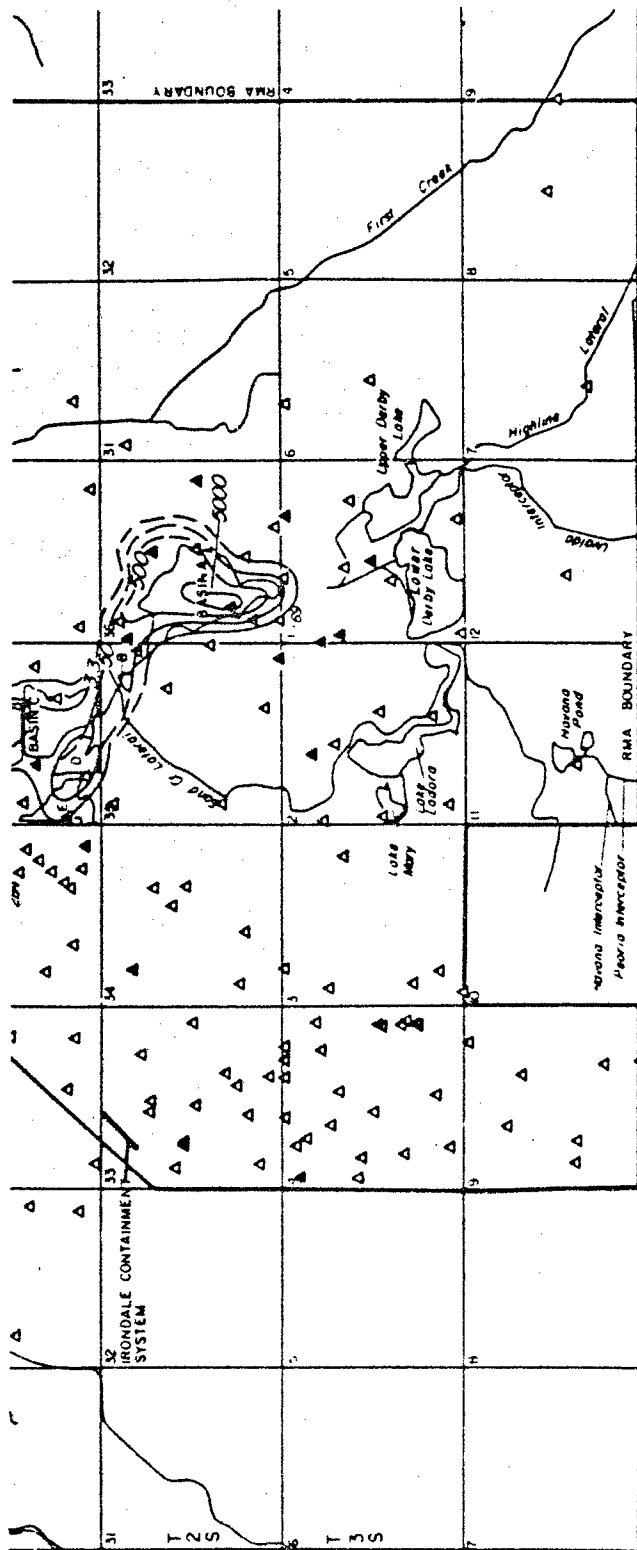
Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland





SOURCE: HLA, 1988d





EXPLANATION

- △ Alluvial Well
- ▲ Unconfined Denver Formation Well
- Isoconcentration Line, Dashed Where Inferred
- △/59 Isolated Detection Or Detection Less Than Highest CRL, in ug/l
- Contour Interval Varies

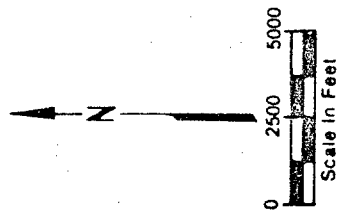
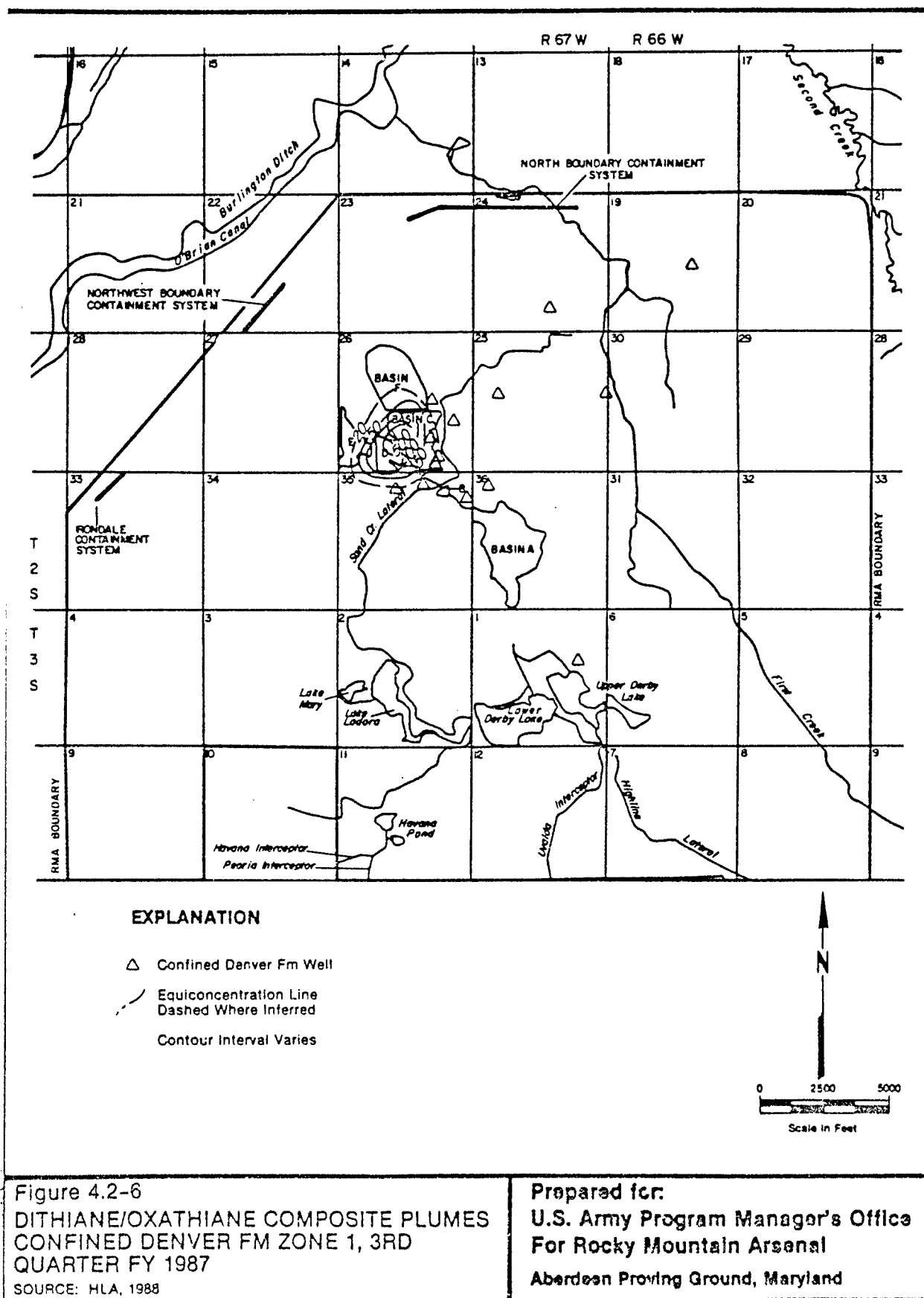


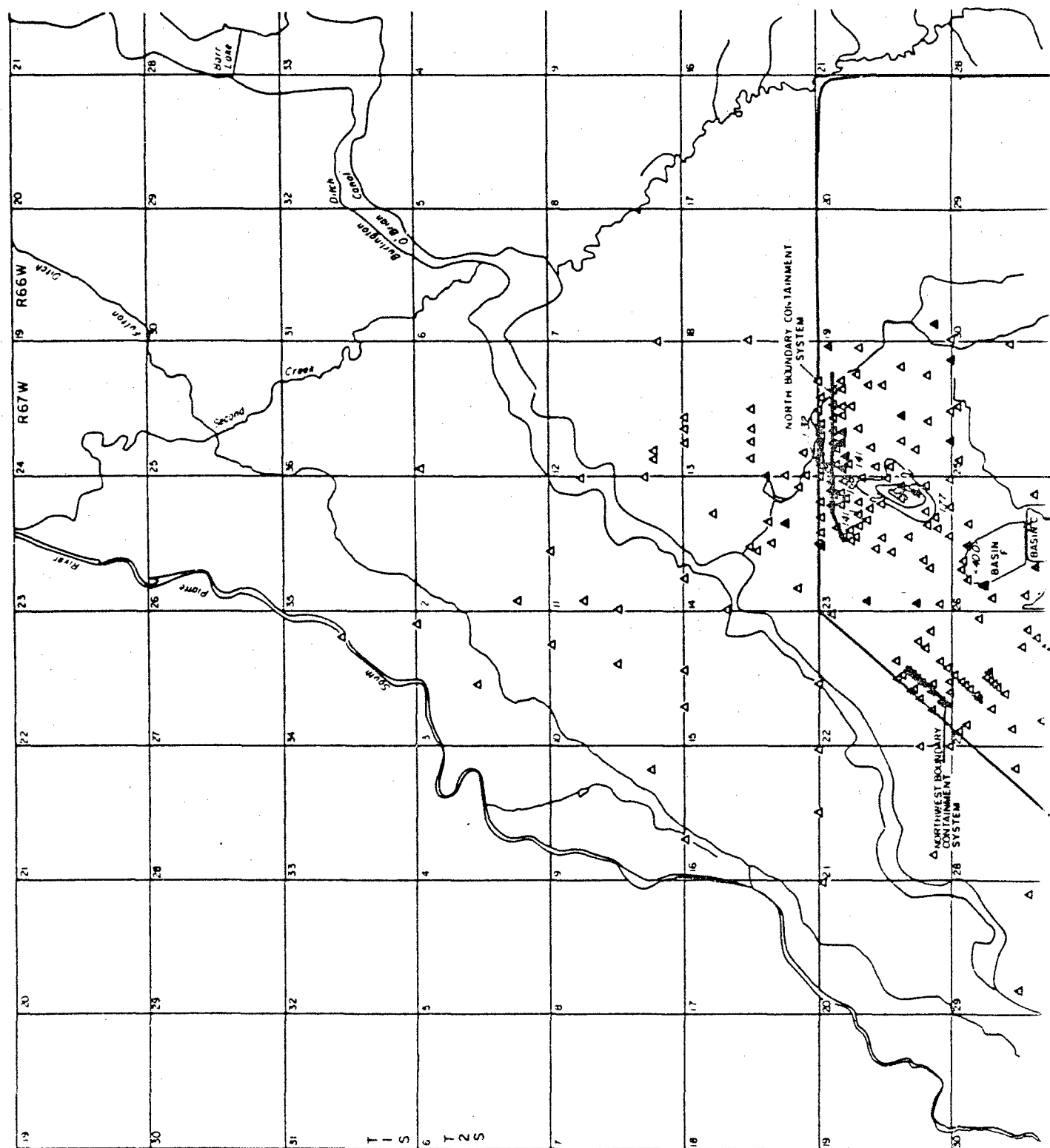
Figure 4.2-5

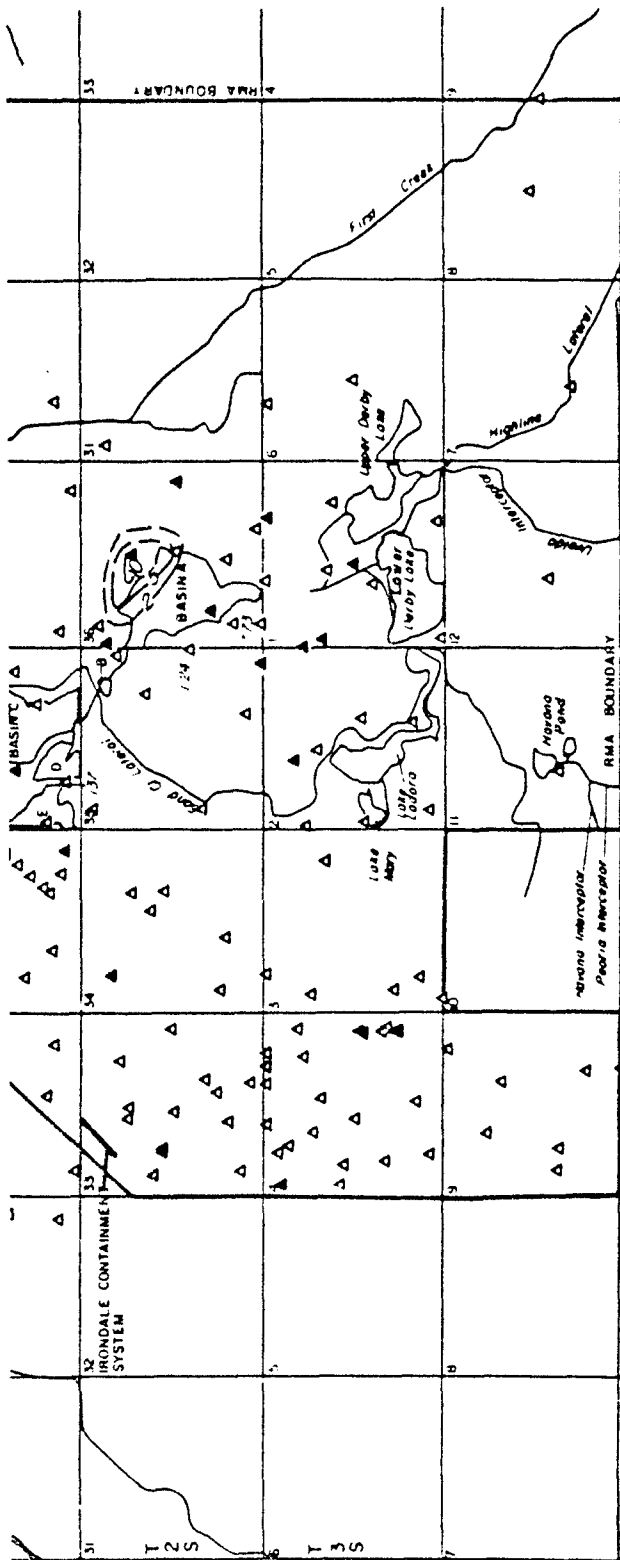
DITHIANE/OXATHIANE PLUMES UNCONFINED GROUNDWATER FLOW SYSTEM, 3RD QUARTER FY 1987

SOURCE: HLA, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland







EXPLANATION

- △ Alluvial Well
- ▲ Unconfined Denver Formation Well
- Isoconcentration Line, Dashed Where Interred
- Isolated Detection Or Deflection Less Than Highest CRL, In u/g/l
- ~~~~~ Contour Interval Varies

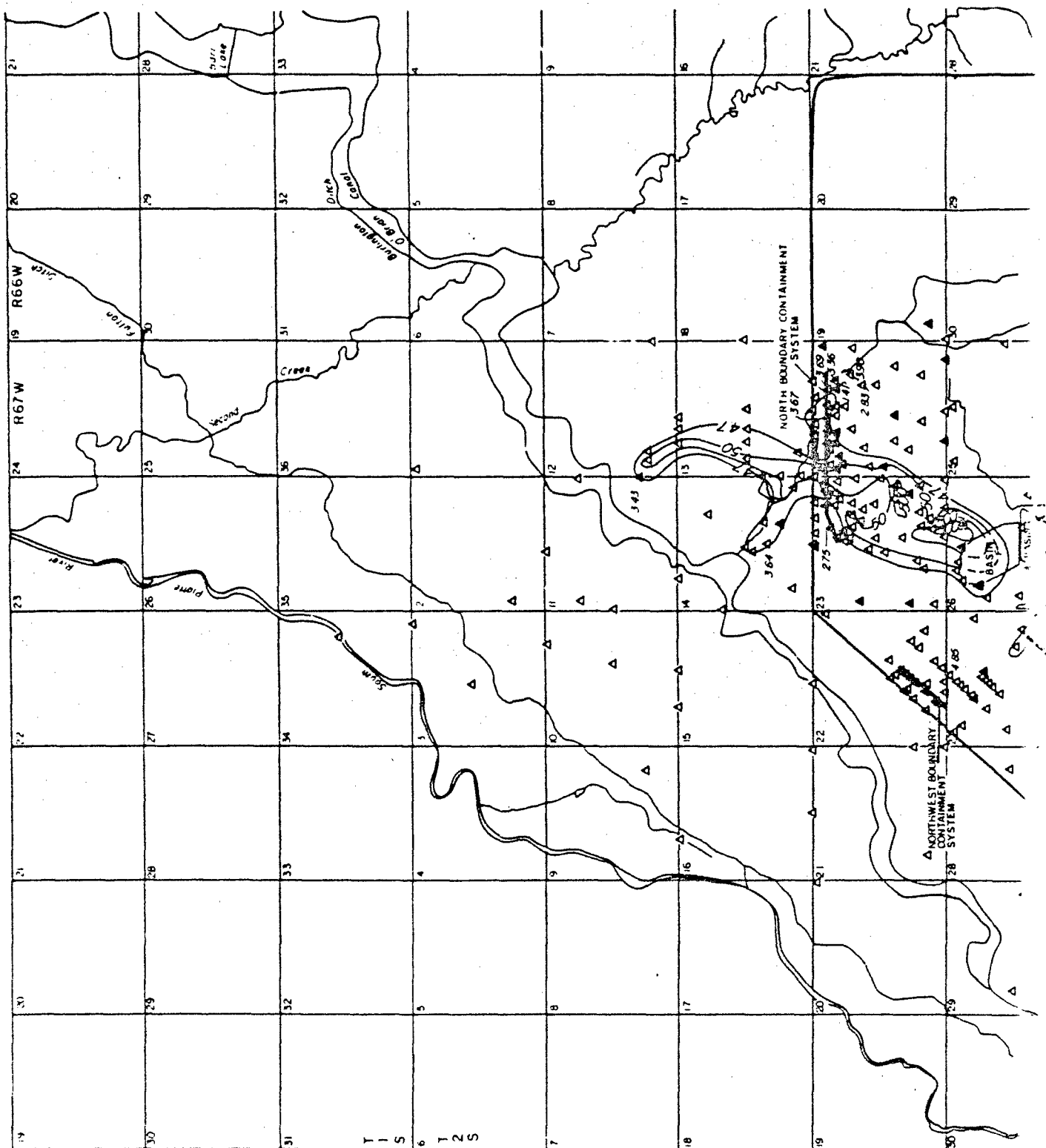
Figure 4.2-7

BENZOTHAZOLE PLUMES UNCONFINED GROUNDWATER FLOW SYSTEM, 3RD QUARTER FY 1987

SOURCE: HLA, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal

Aberdeen Proving Ground, Maryland



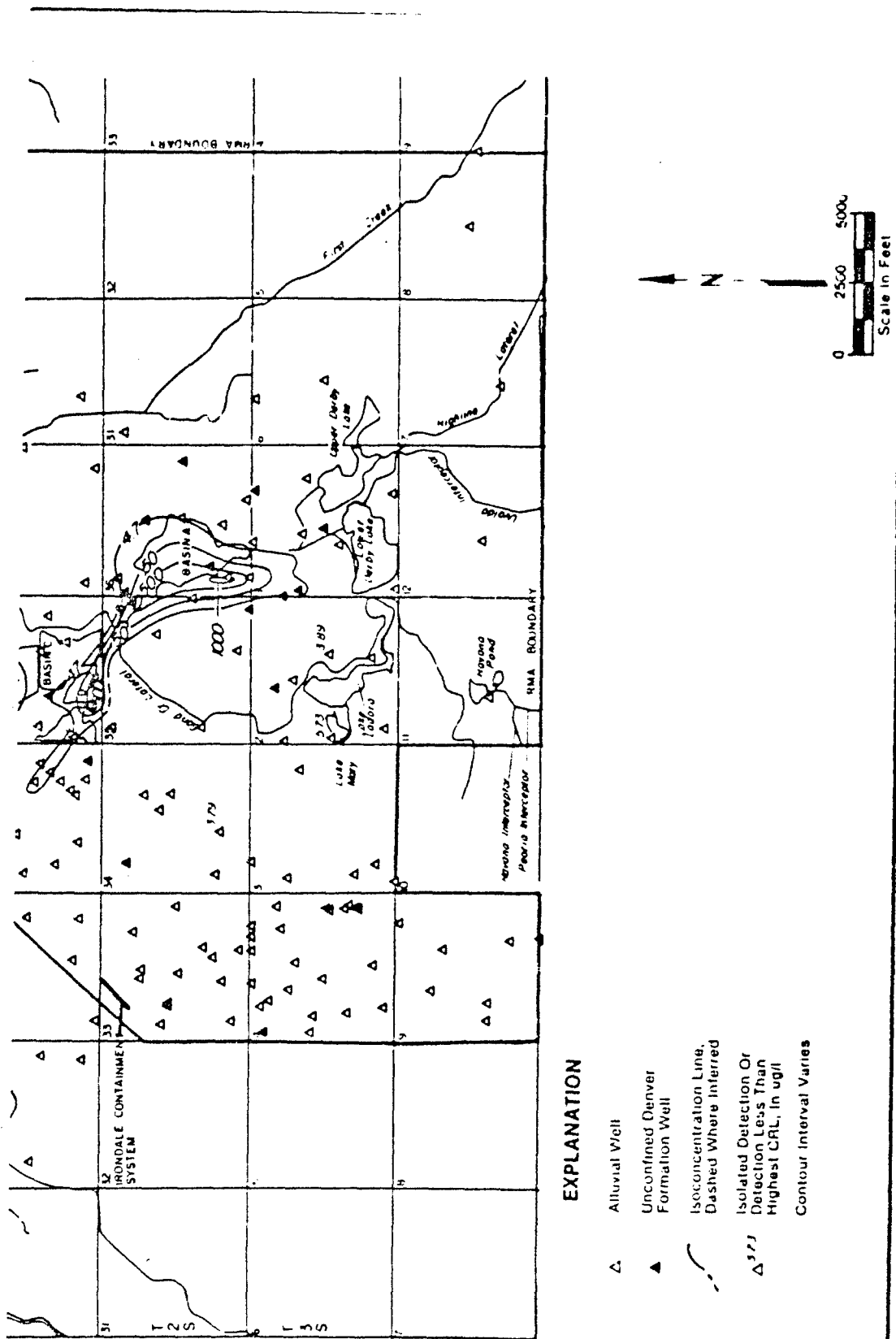
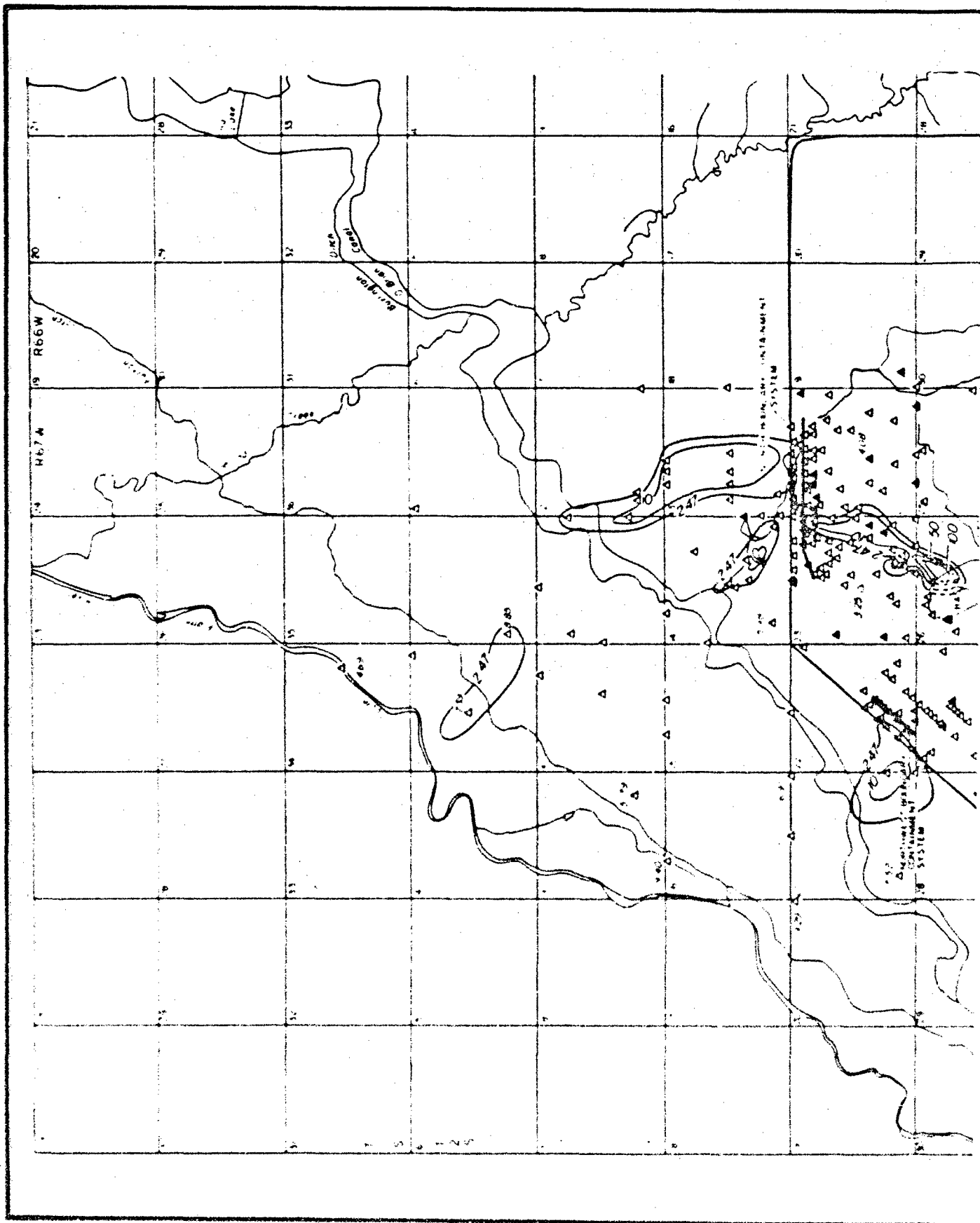
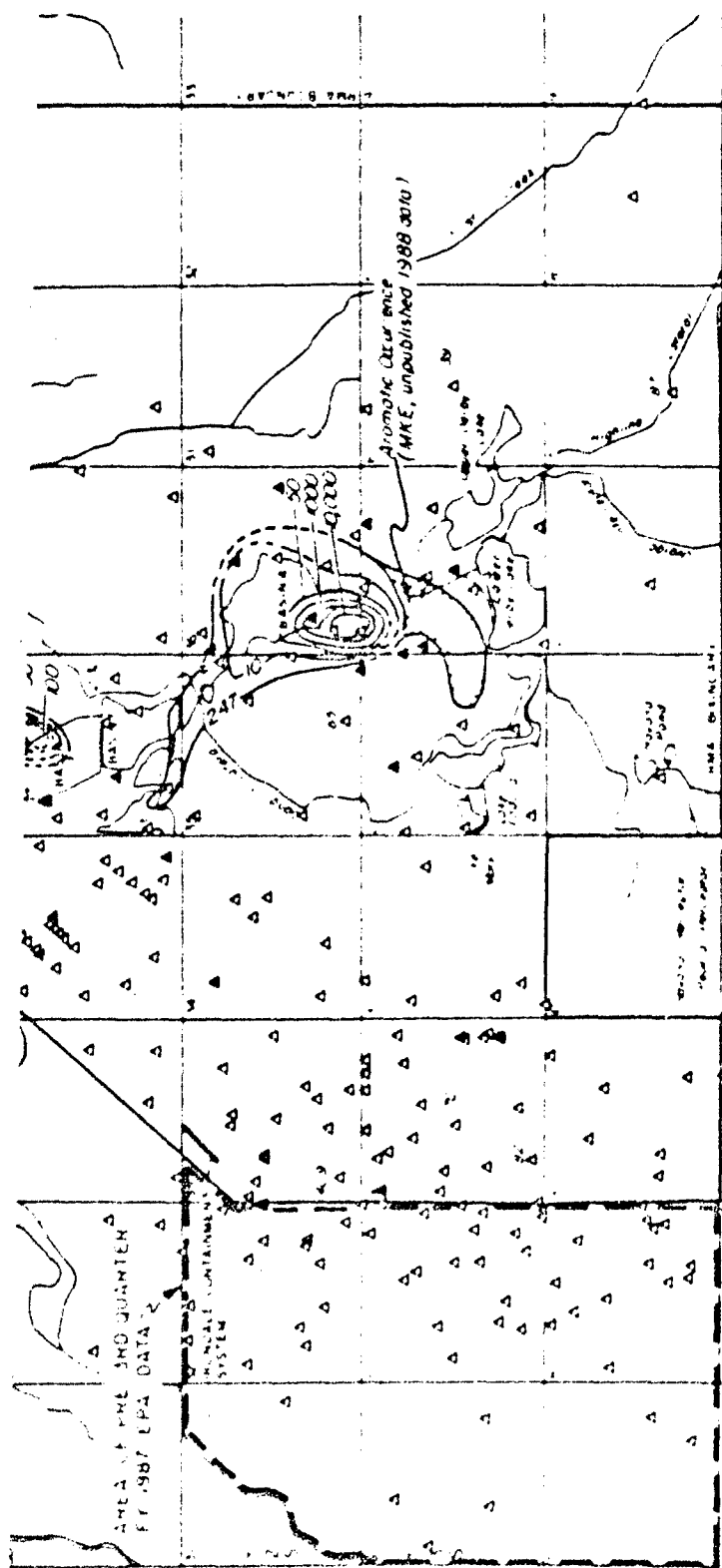


Figure 4.2-8

ORGANOSULFUR COMPOUNDS (CPMS, CPMSO, CPMSO₂) PLUMES
 UNCONFINED GROUNDWATER FLOW SYSTEM, 3RD QUARTER FY 1987

SOURCE: HLA, 1988

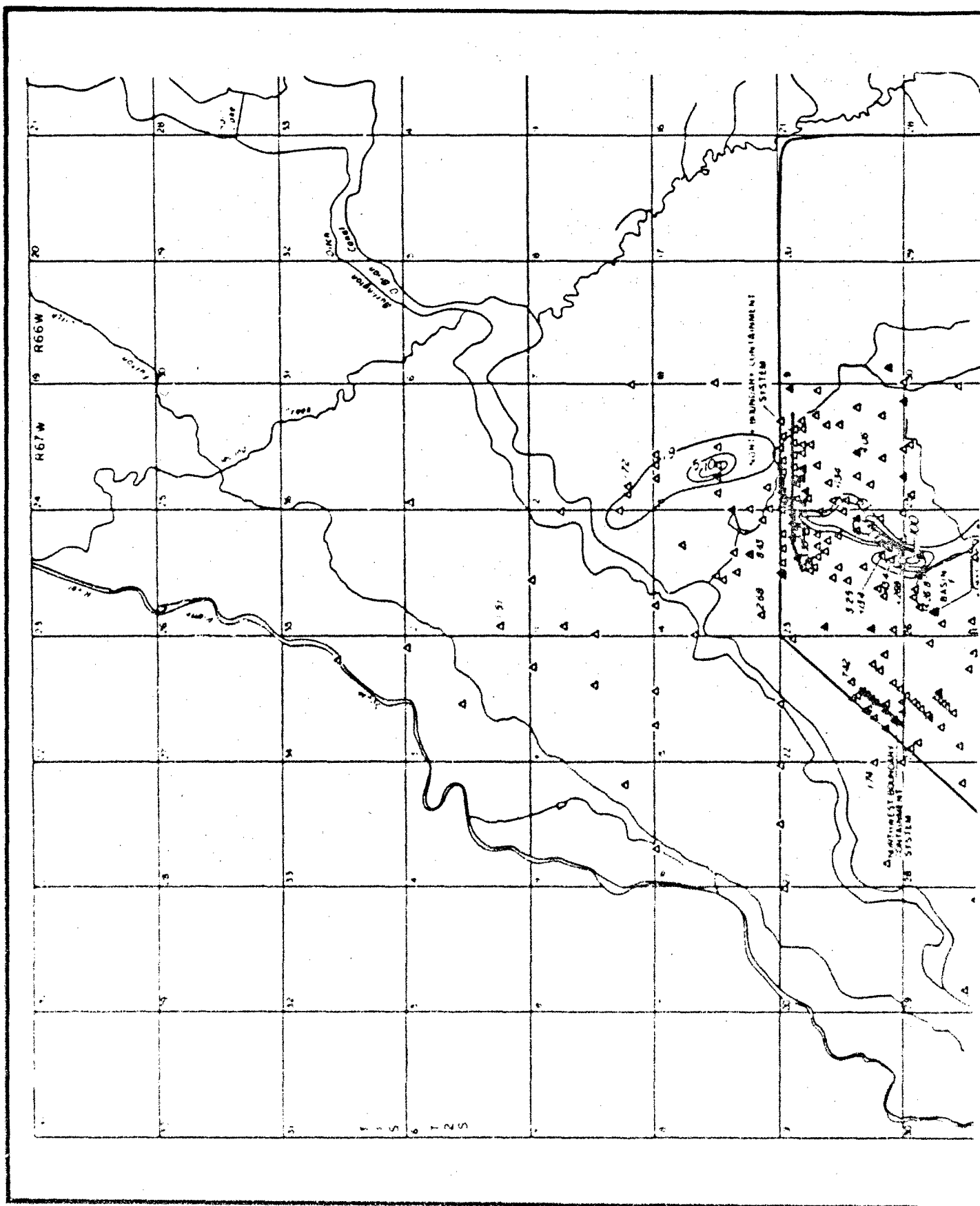


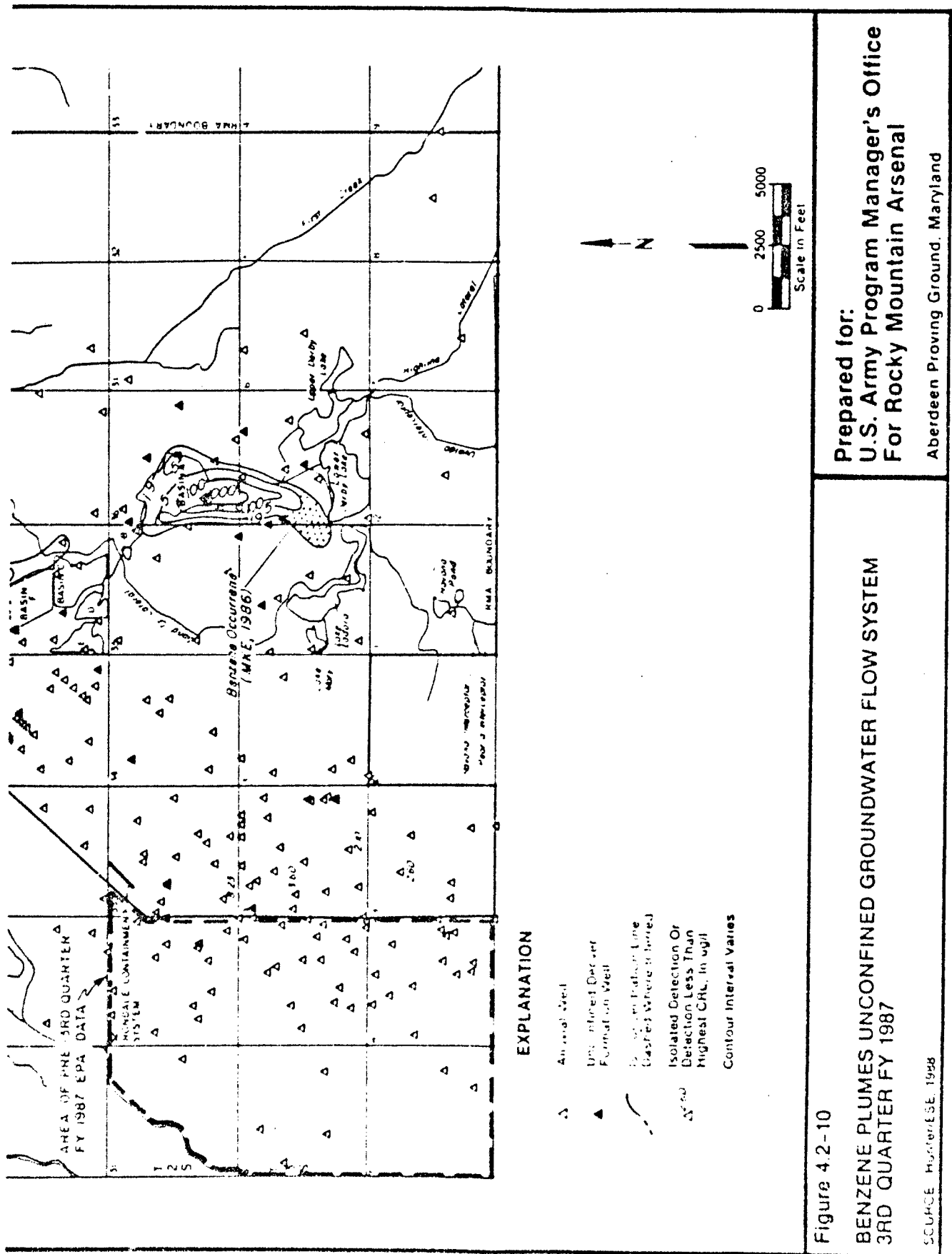


Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground Maryland

Figure 4.2-9
SUMMED VOLATILE AROMATICS PLUMES UNCONFINED GROUNDWATER
FLOW SYSTEM, 3RD QUARTER, FY 1987

DATE: 11/13/87





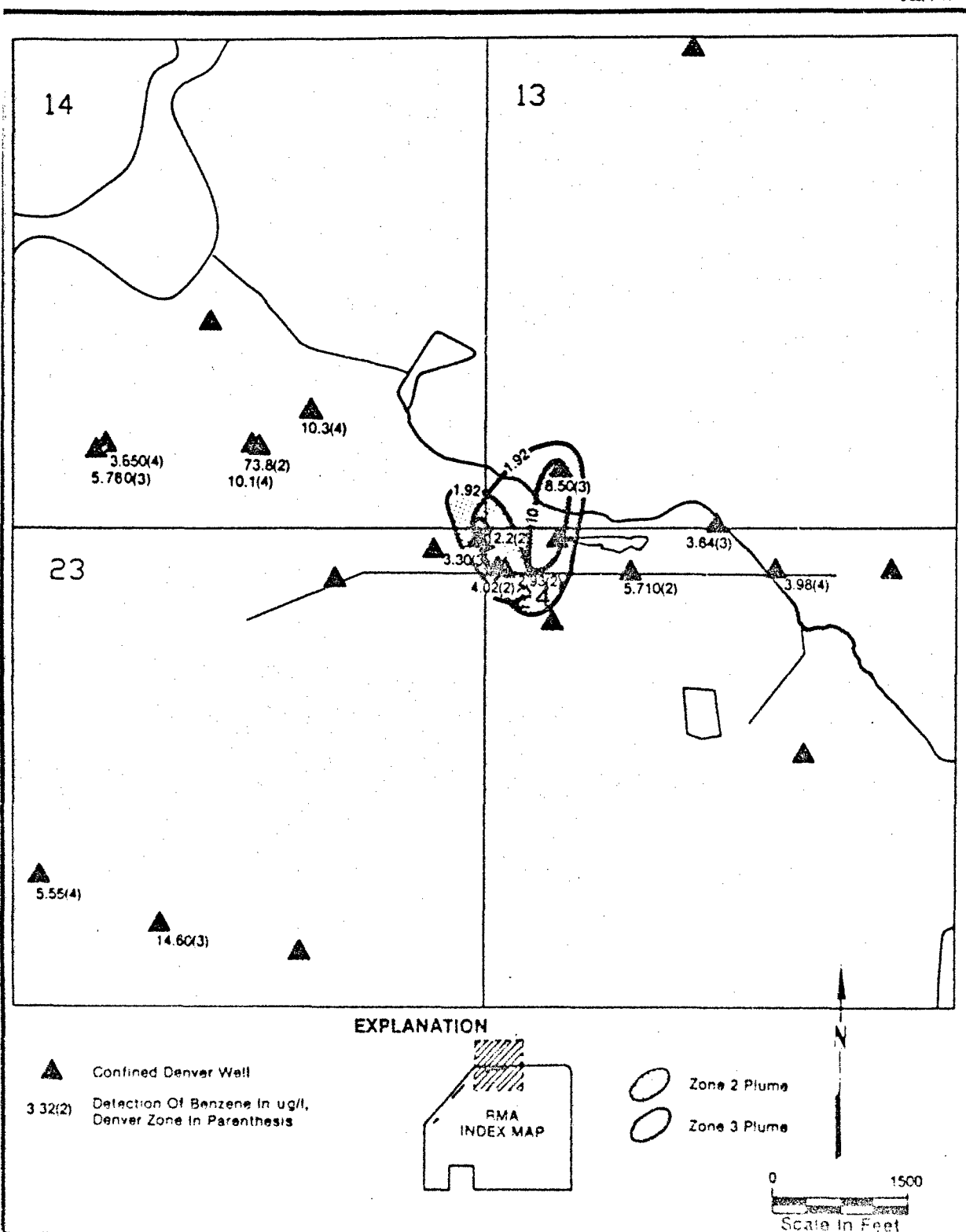
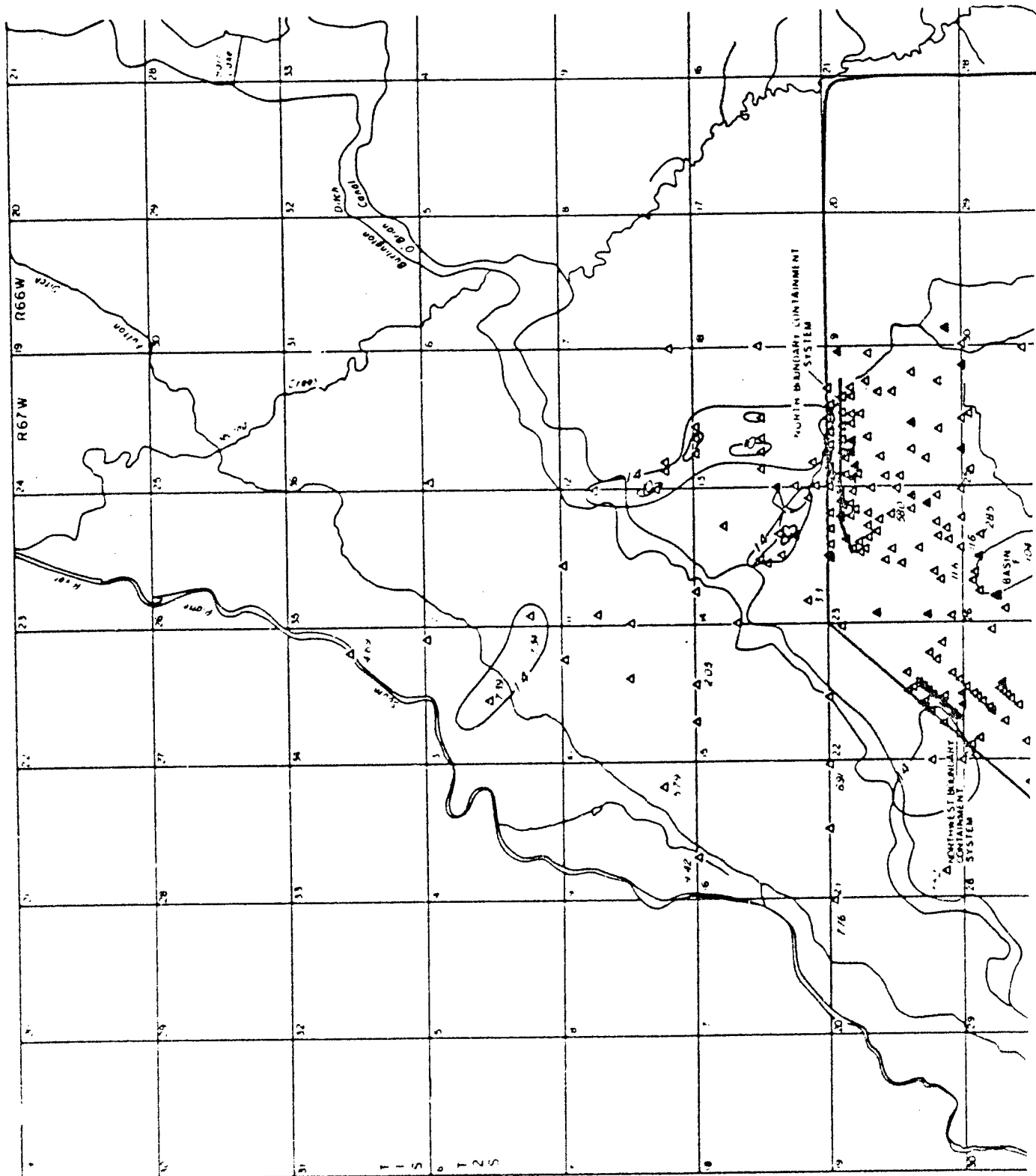
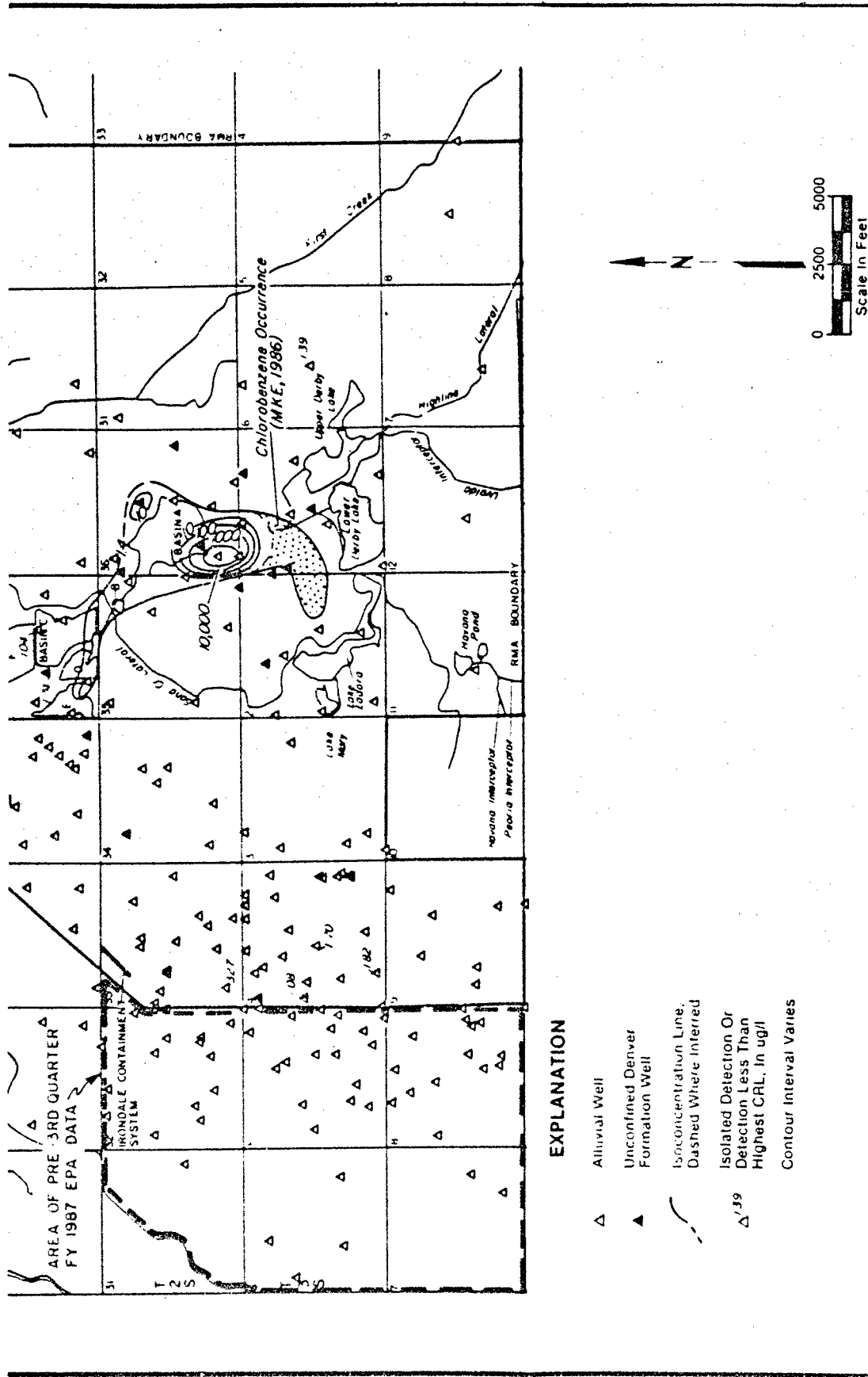


Figure 4.2-11
 BENZENE IN CONFINED PORTIONS OF
 DENVER ZONES 2,3, and 4

SOURCE: Hunter/ESE, 1988

Prepared for:
 U.S. Army Program Manager's Office
 For Rocky Mountain Arsenal
 Aberdeen Proving Ground, Maryland





EXPLANATION

- △ Alluvial Well
- ▲ Unconfined Denver Formation Well
- Isoconcentration Line, Dashed Where Inferred
- △^{1/39} Isolated Detection Or Detection Less Than Highest CRL In ug/l
- Contour Interval Varies

Figure 4.2-12

CHLOROBENZENE PLUMES UNCONFINED GROUNDWATER FLOW
SYSTEM, 3RD QUARTER FY 1987

SOURCE: Hunter/ESE, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland

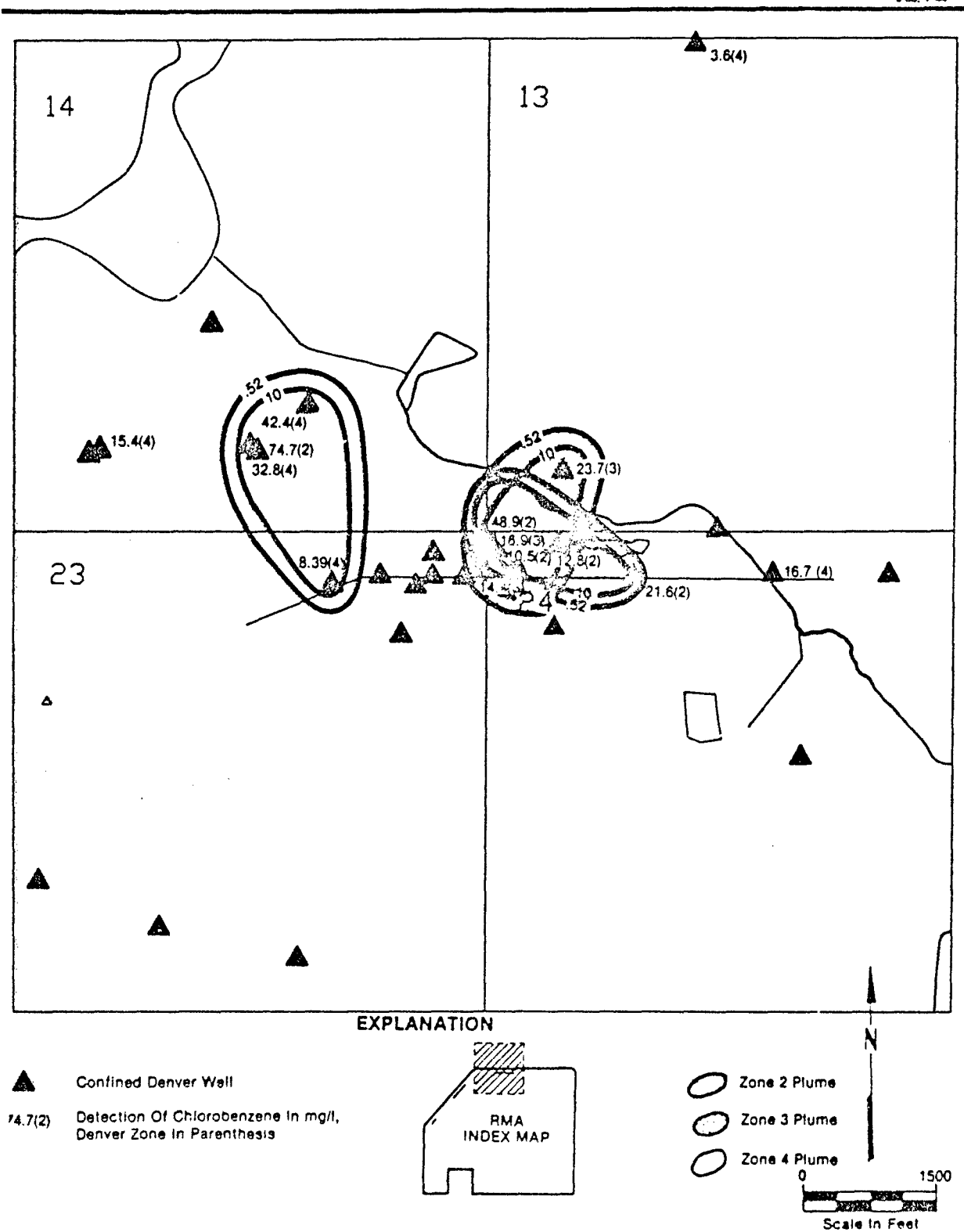
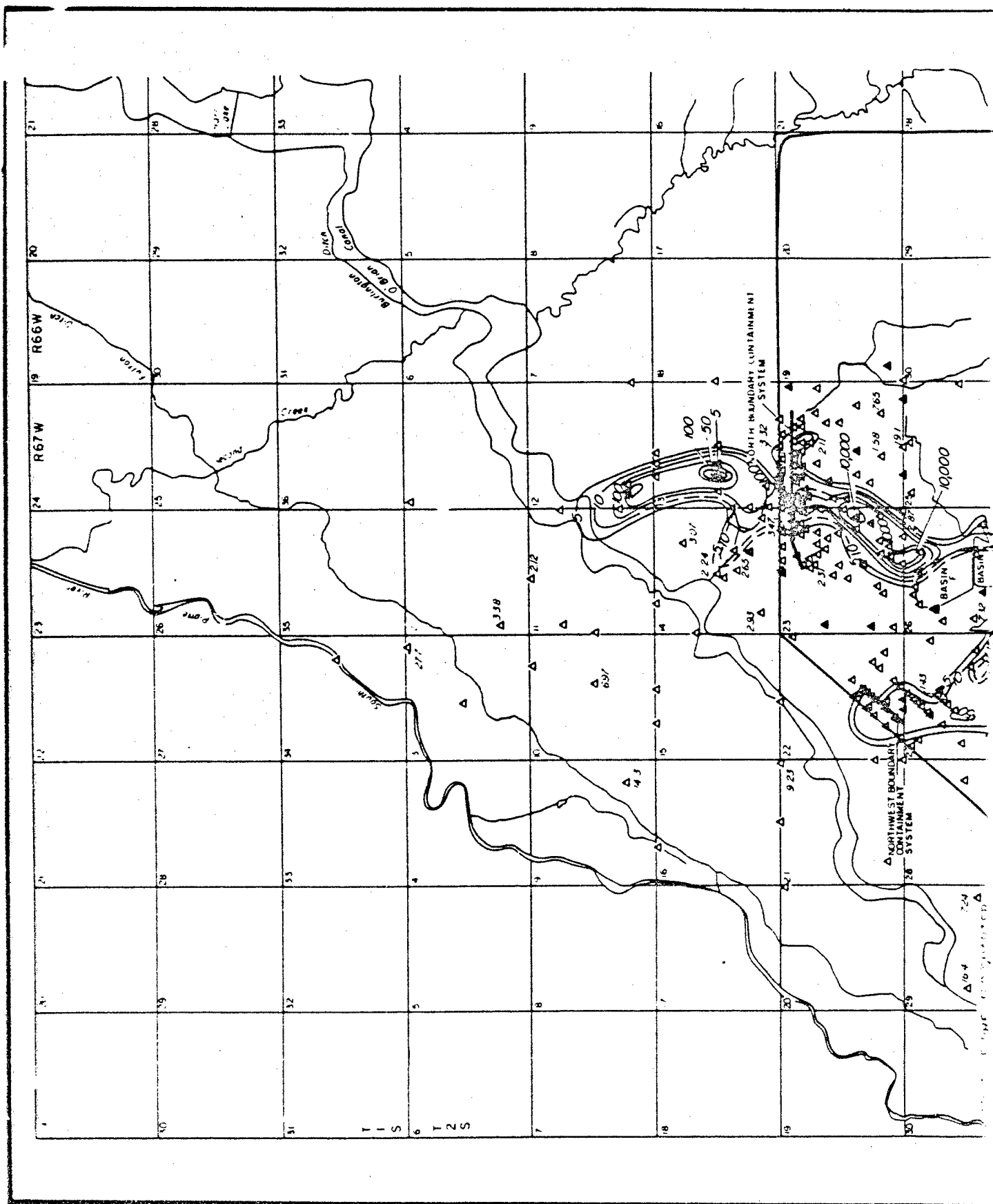
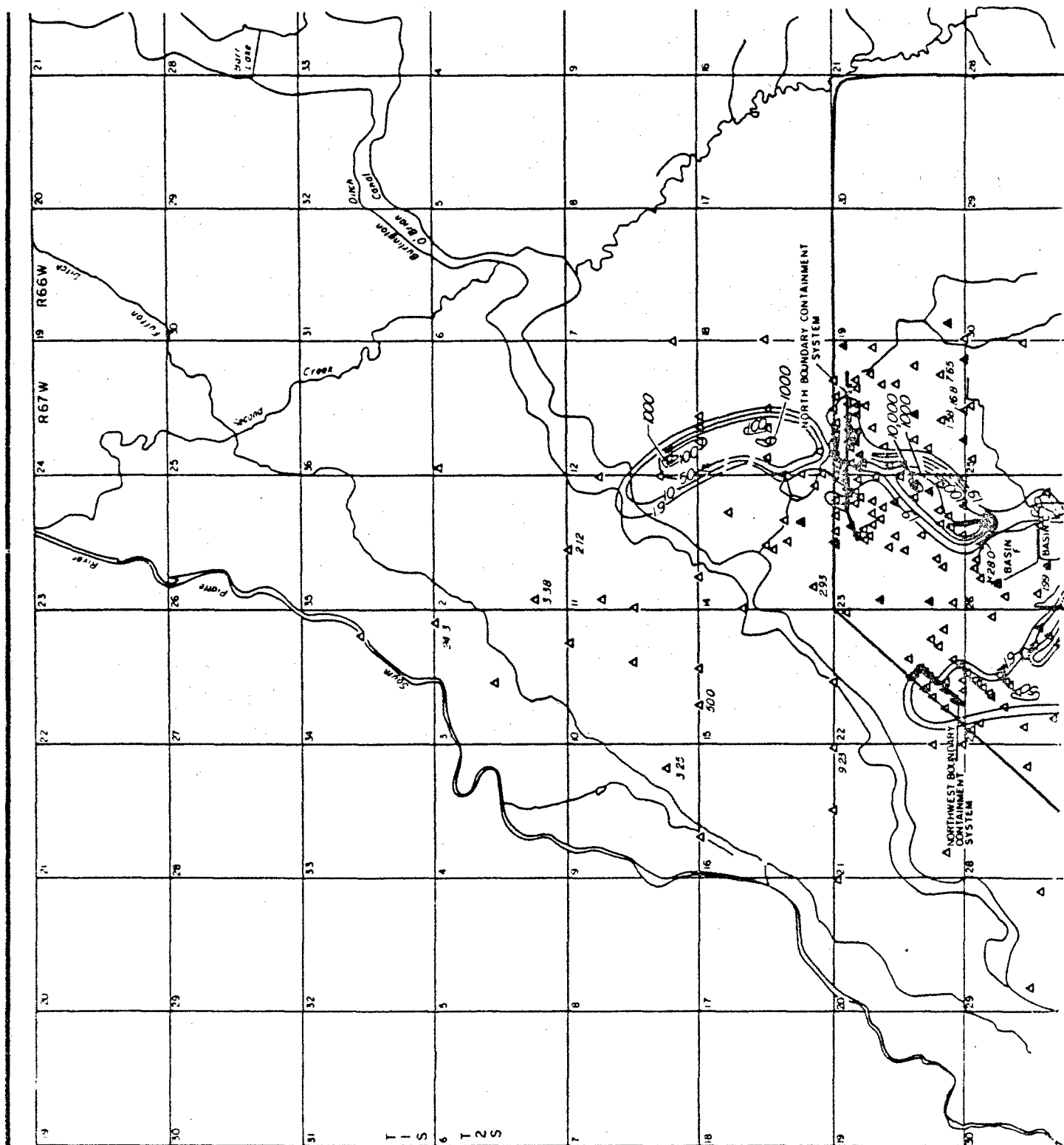


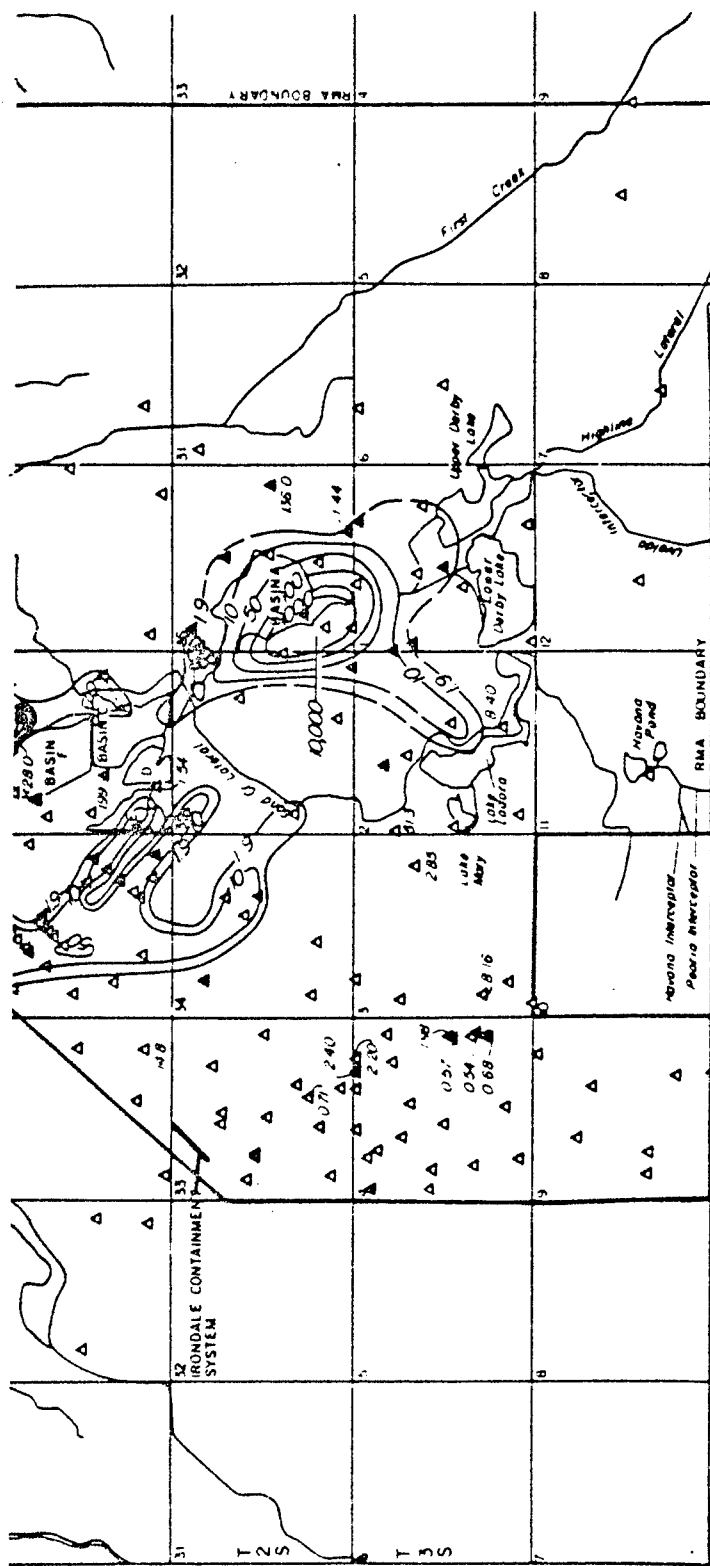
Figure 4.2-13
CHLOROBENZENE IN CONFINED PORTIONS
OF DENVER ZONES 2, 3 and 4

SOURCE: Hunter/ESE, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland







EXPLANATION

- △ Alluvial Well
- ▲ Unconfined Denver Formation Well
- Isocentration Line, Dashed Where Inferred
- △ 40 Isolated Detection Or Detection Less Than Highest CRL, In ug/l
- Contour Interval Varies

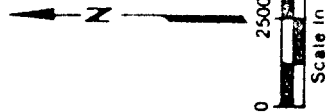
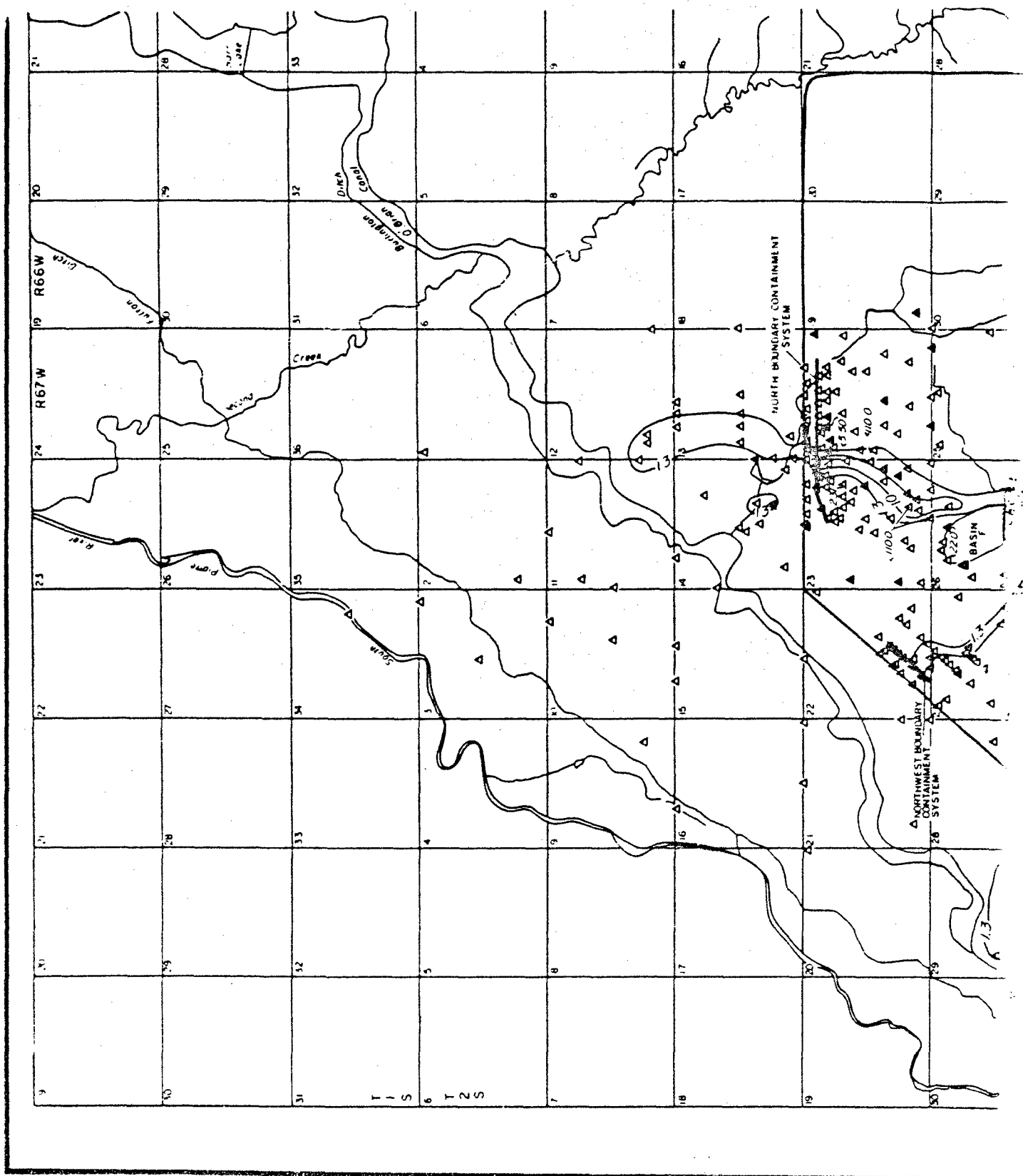


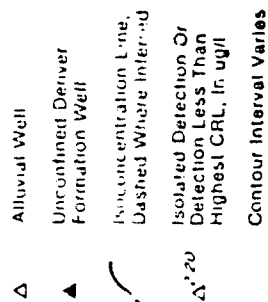
Figure 4.2-15

CHLOROFORM PLUMES UNCONFINED GROUNDWATER FLOW SYSTEM 3RD QUARTER FY 1987

SOURCE: Hunter/ISE, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland



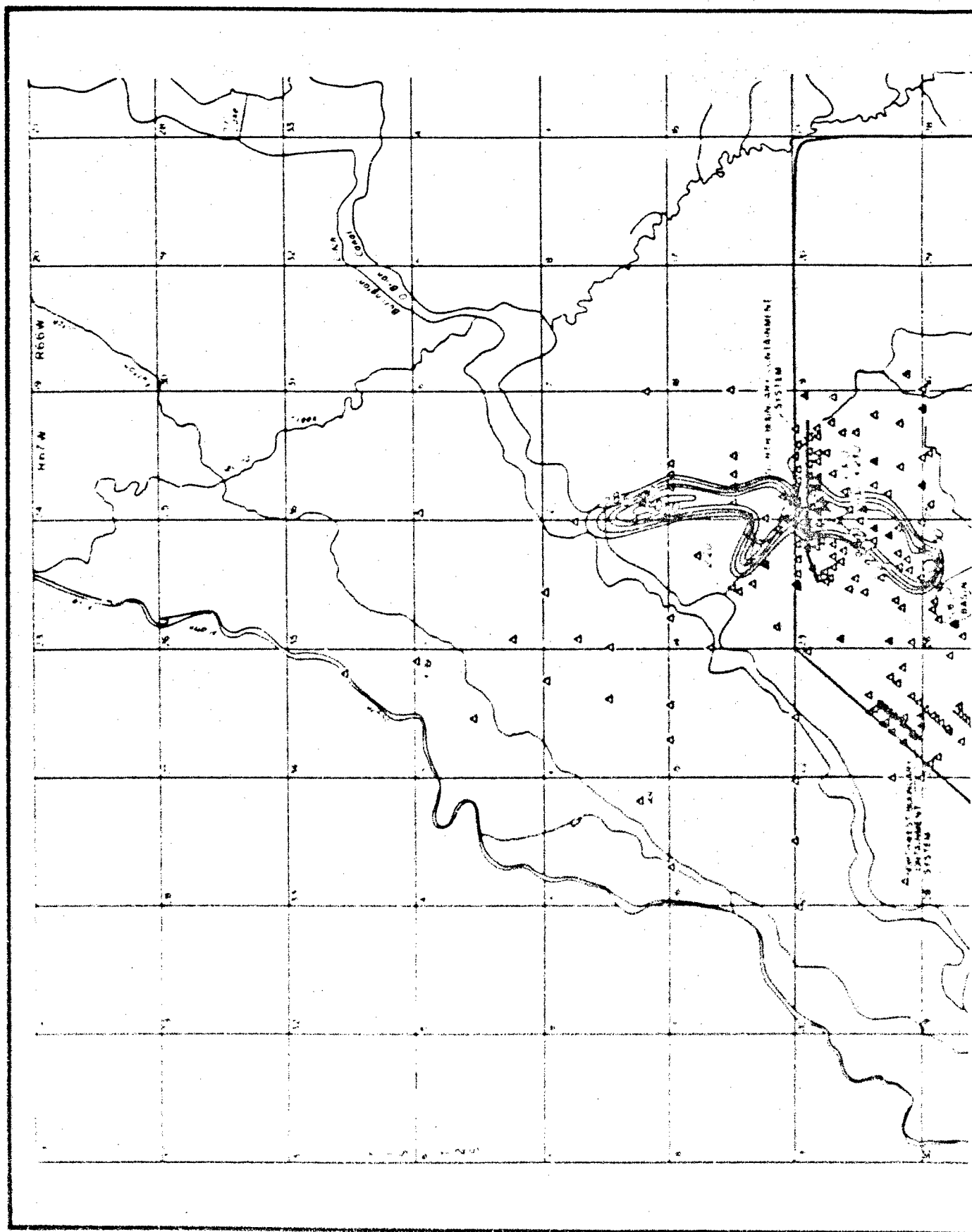


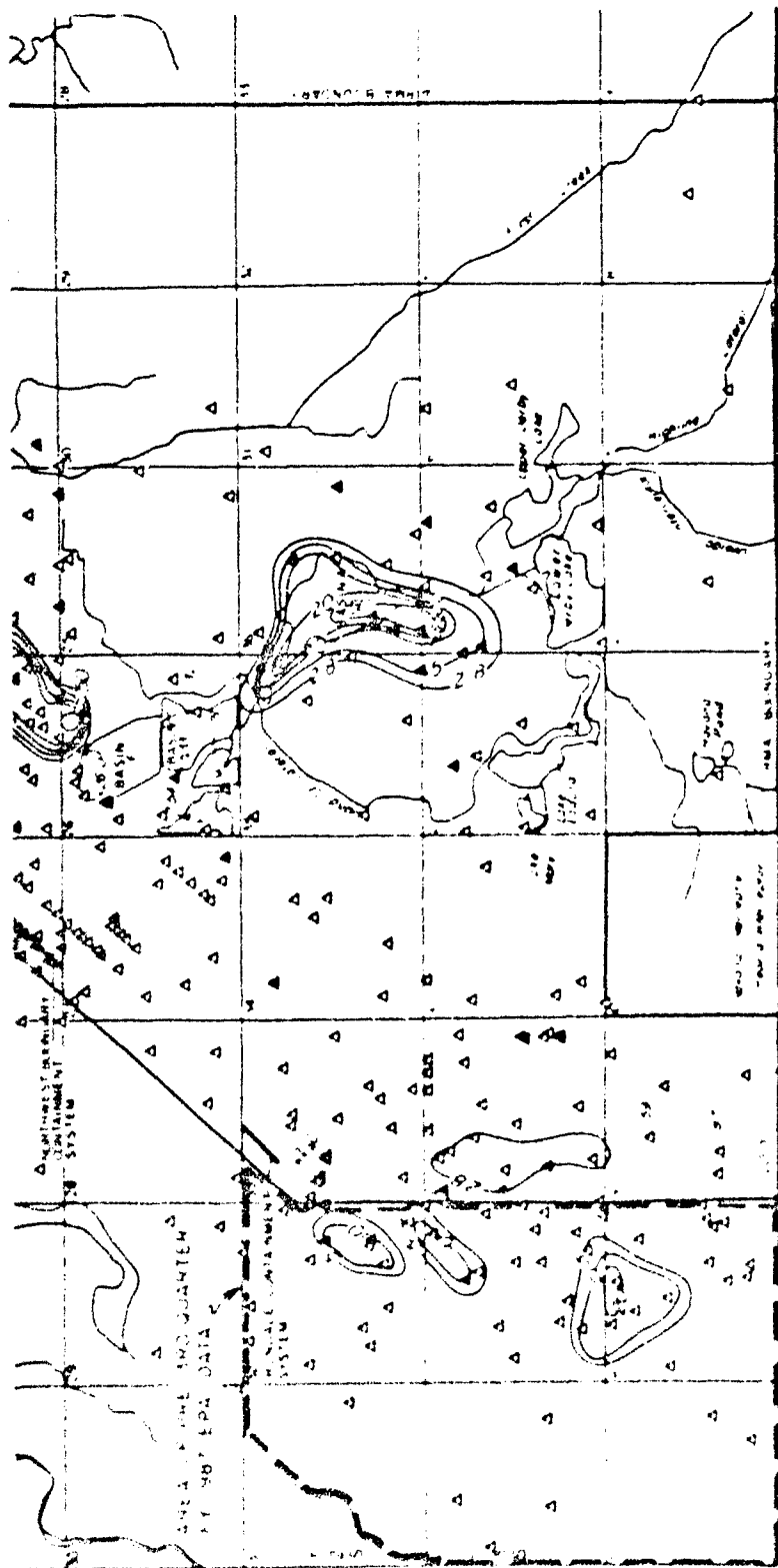
A vertical scale in feet with markings at 0, 2500, and 5000.

TRICHLOROETHYLENE PLUMES UNCONFINED GROUNDWATER
FLOW SYSTEM, 3RD QUARTER FY 1987

SOURCE: HUNTER/HESE, 1988

**Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland**





EXPLANATION

- ▲ Active Well
- ▲ Tetrachloroethylene Plume
- Contour Line
- Detected Concentration
- Detected Concentration Or Detection Less Than 1000 µg/L (10 µg/L)
- Contour Interval Values

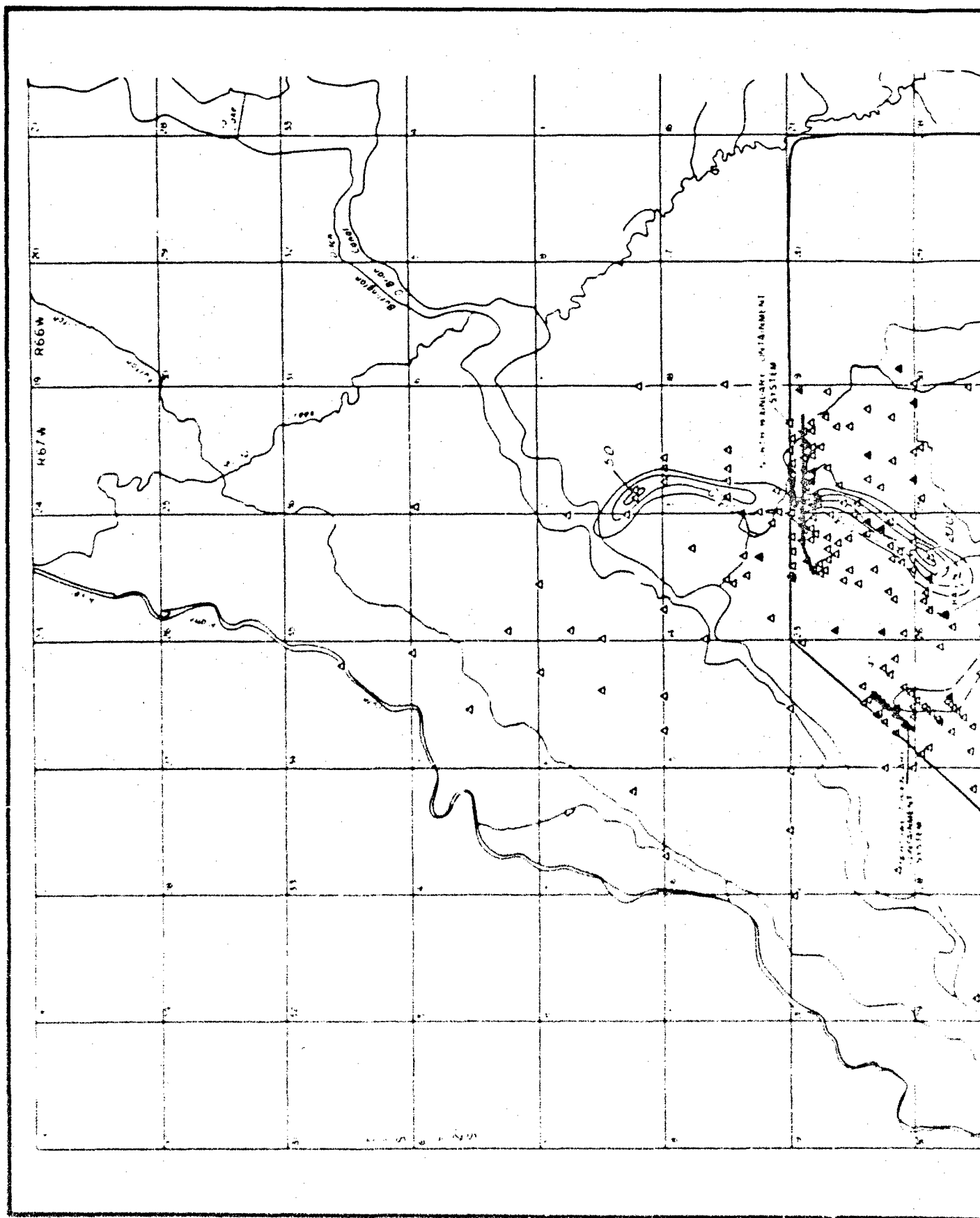
Figure 4.2-17

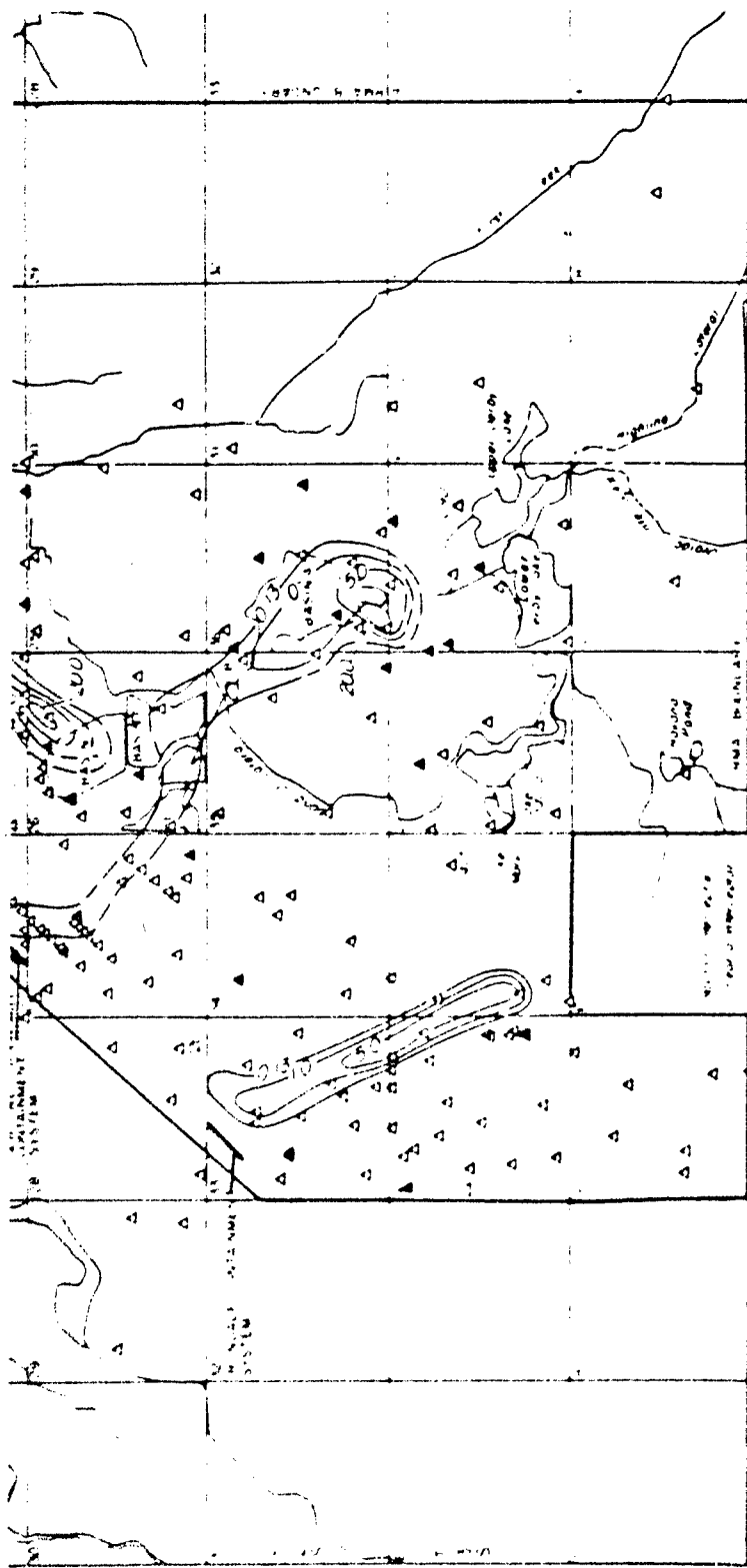
TETRACHLOROETHYLENE PLUMES UNCONFINED GROUNDWATER
FLOW SYSTEM, 3RD QUARTER FY 1987

SOURCE: MONITORING DATA

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal

Aberdeen Proving Ground, Maryland





EXPLANATION

- ▲ Monitoring Well
- Plume Boundary
- - - Detection Limit
- △ Isolated Detection Or Detection Less Than Highest CRL, in ug/l
- Contour Interval Varies

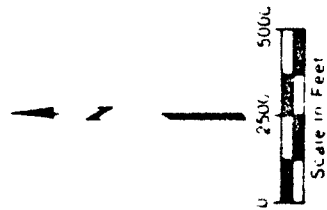


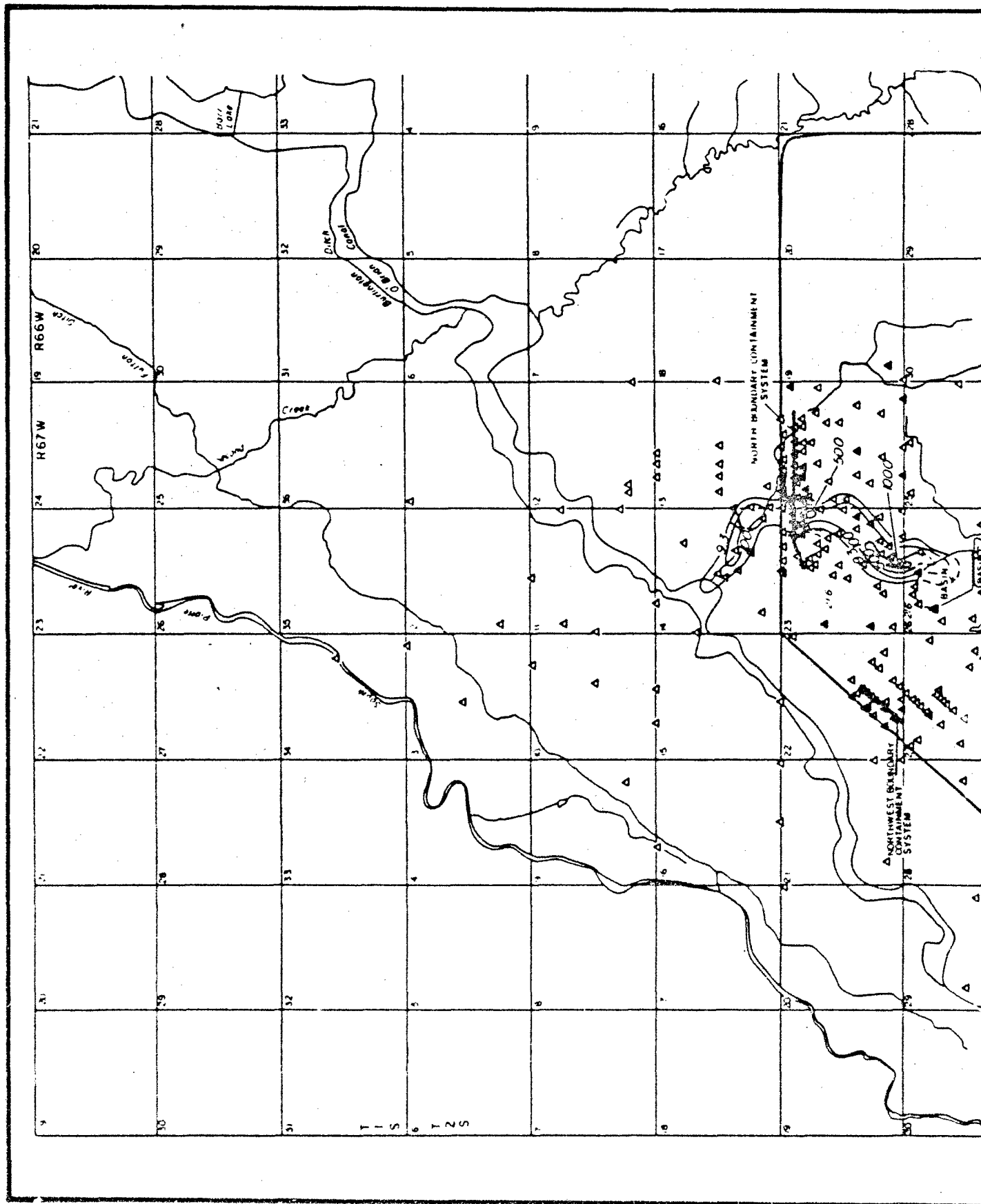
Figure 4.2-18

DIBROMOCHLOROPROPANE PLUMES UNCONFINED GROUNDWATER FLOW SYSTEM, 3RD QUARTER FY 1987

SOURCE: MIA 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal

Aberdeen Proving Ground, Maryland



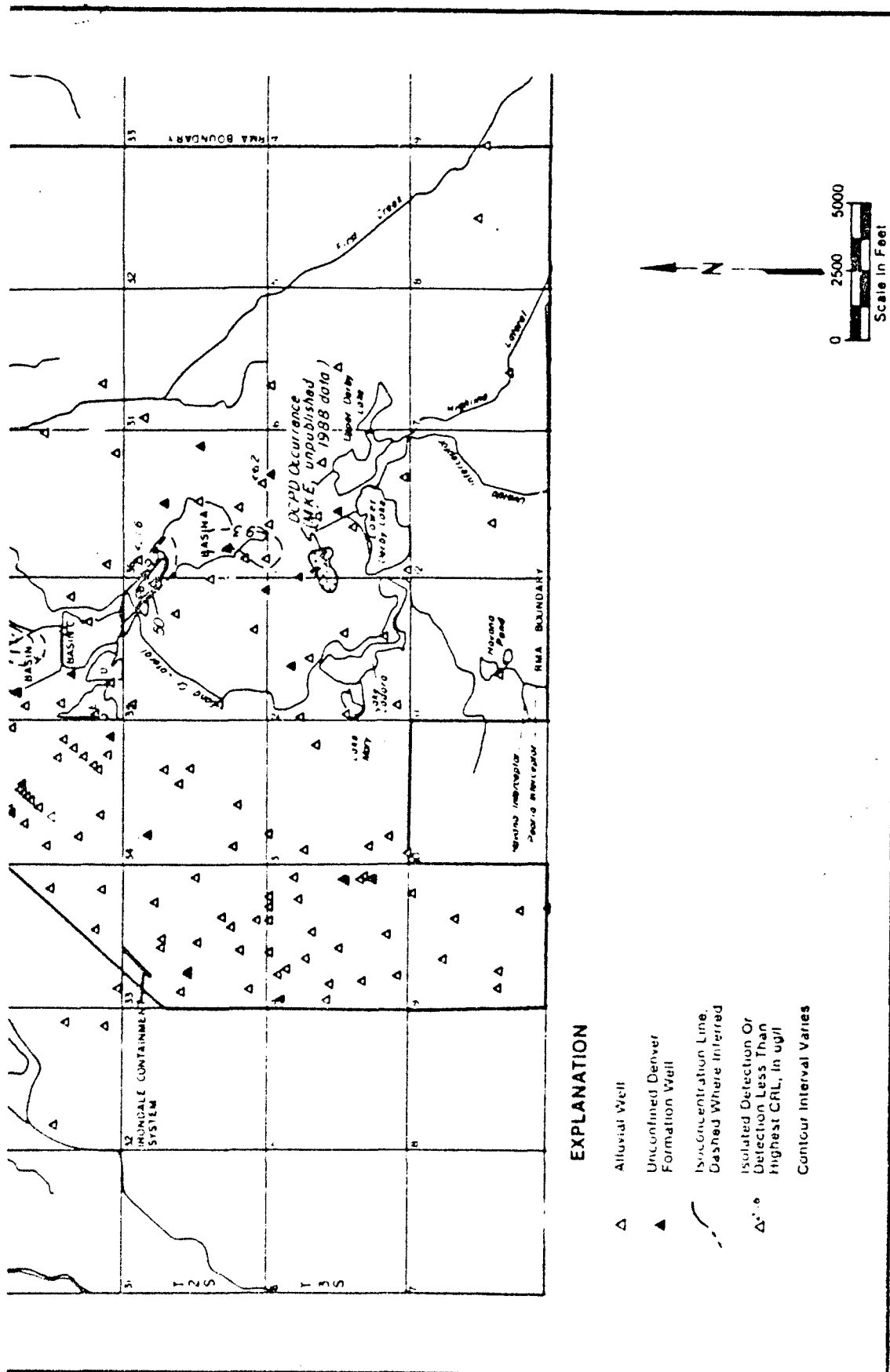


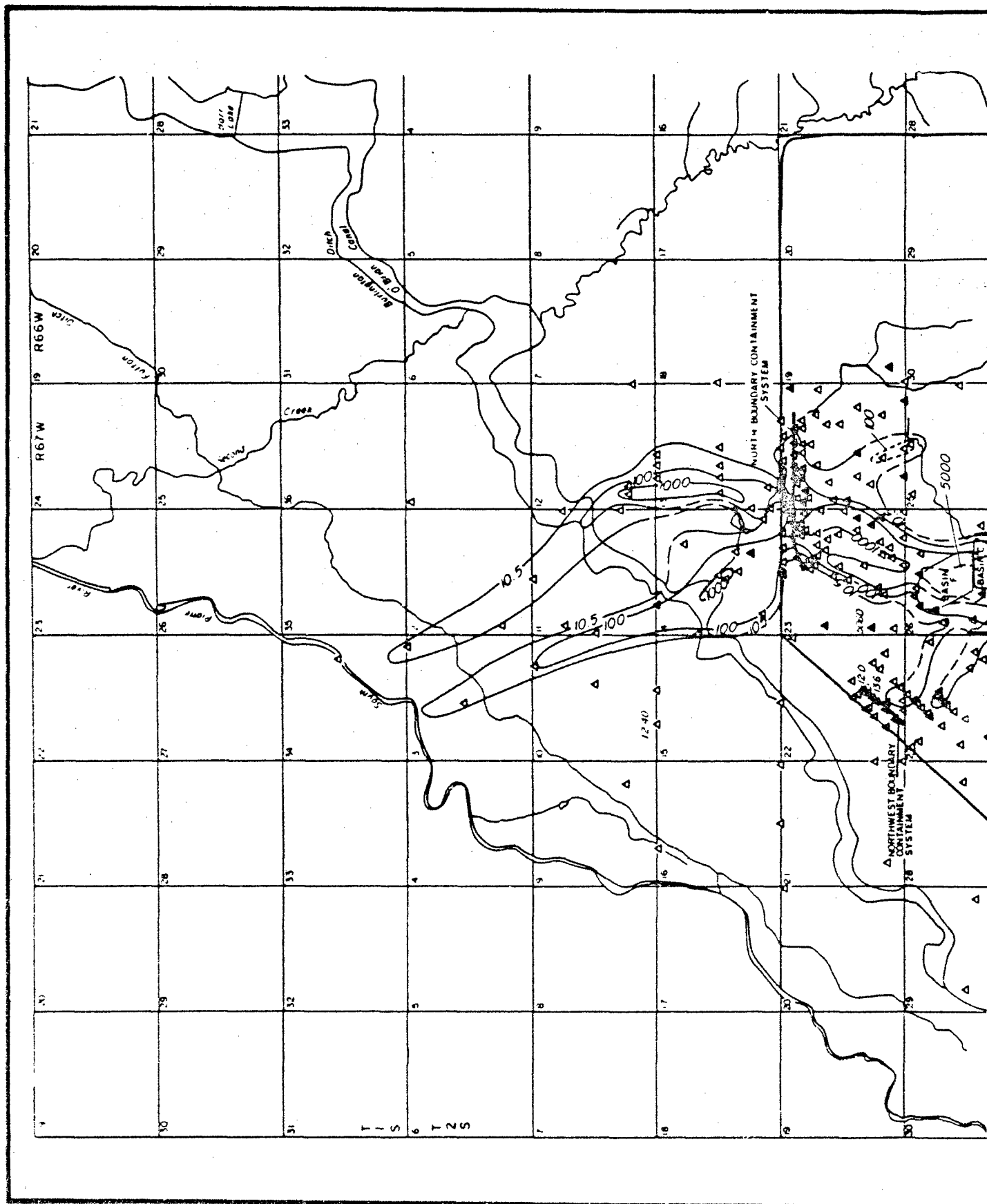
Figure 4.2-19

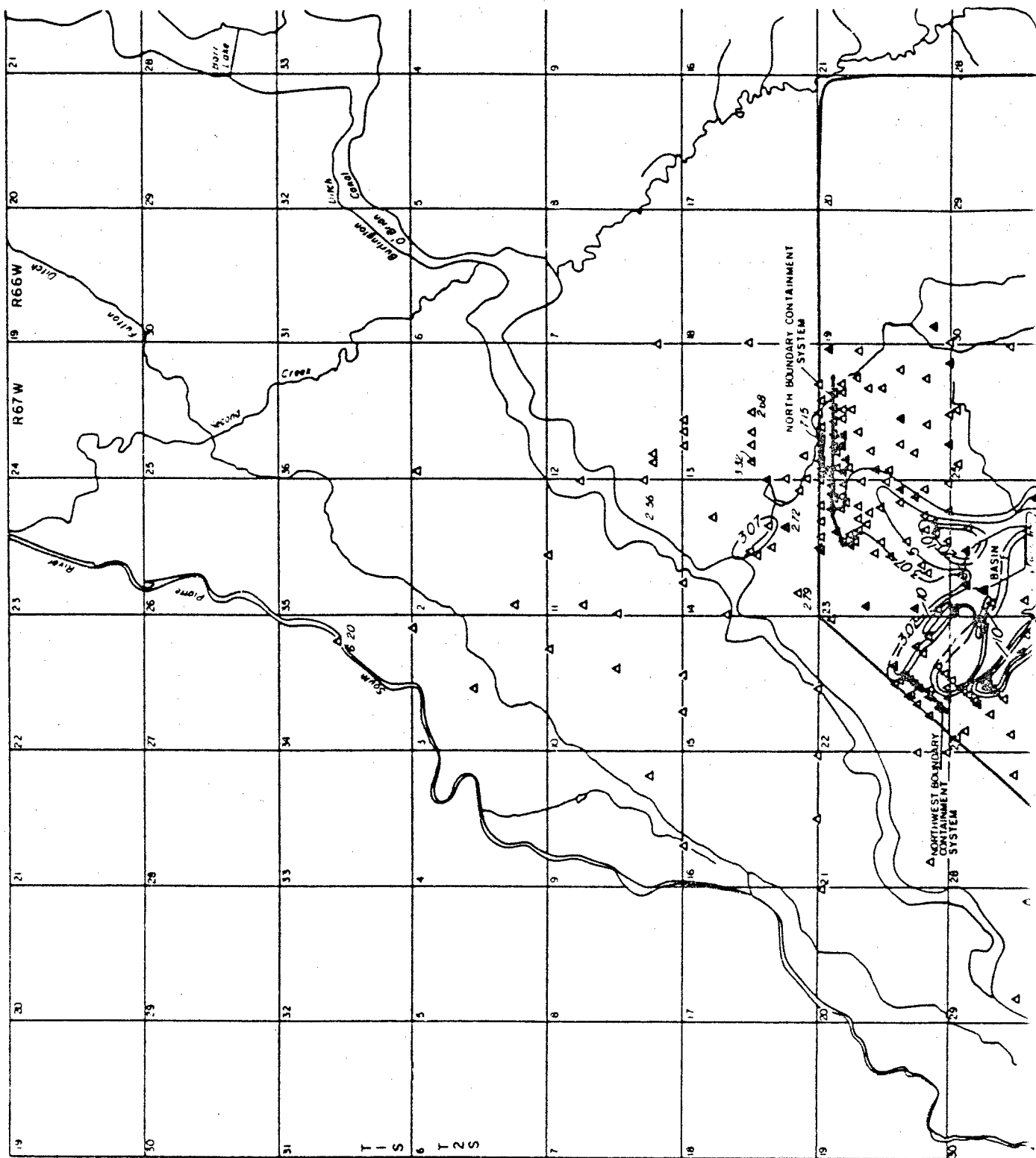
DICYCLOPENTADIENE PLUMES UNCONFINED GROUNDWATER FLOW SYSTEM, 3RD QUARTER FY 1987

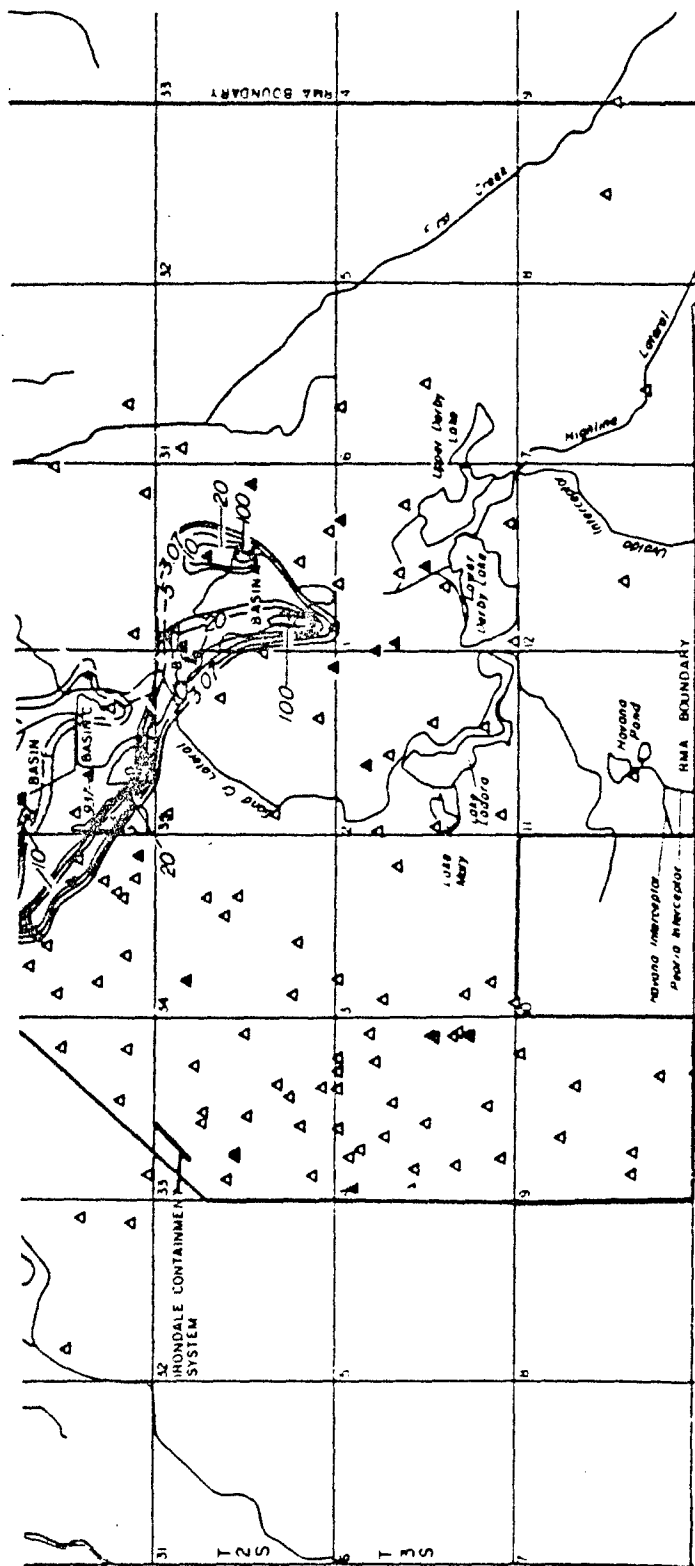
SOURCE: HLA, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal

Aberdeen Proving Ground, Maryland







EXPLANATION

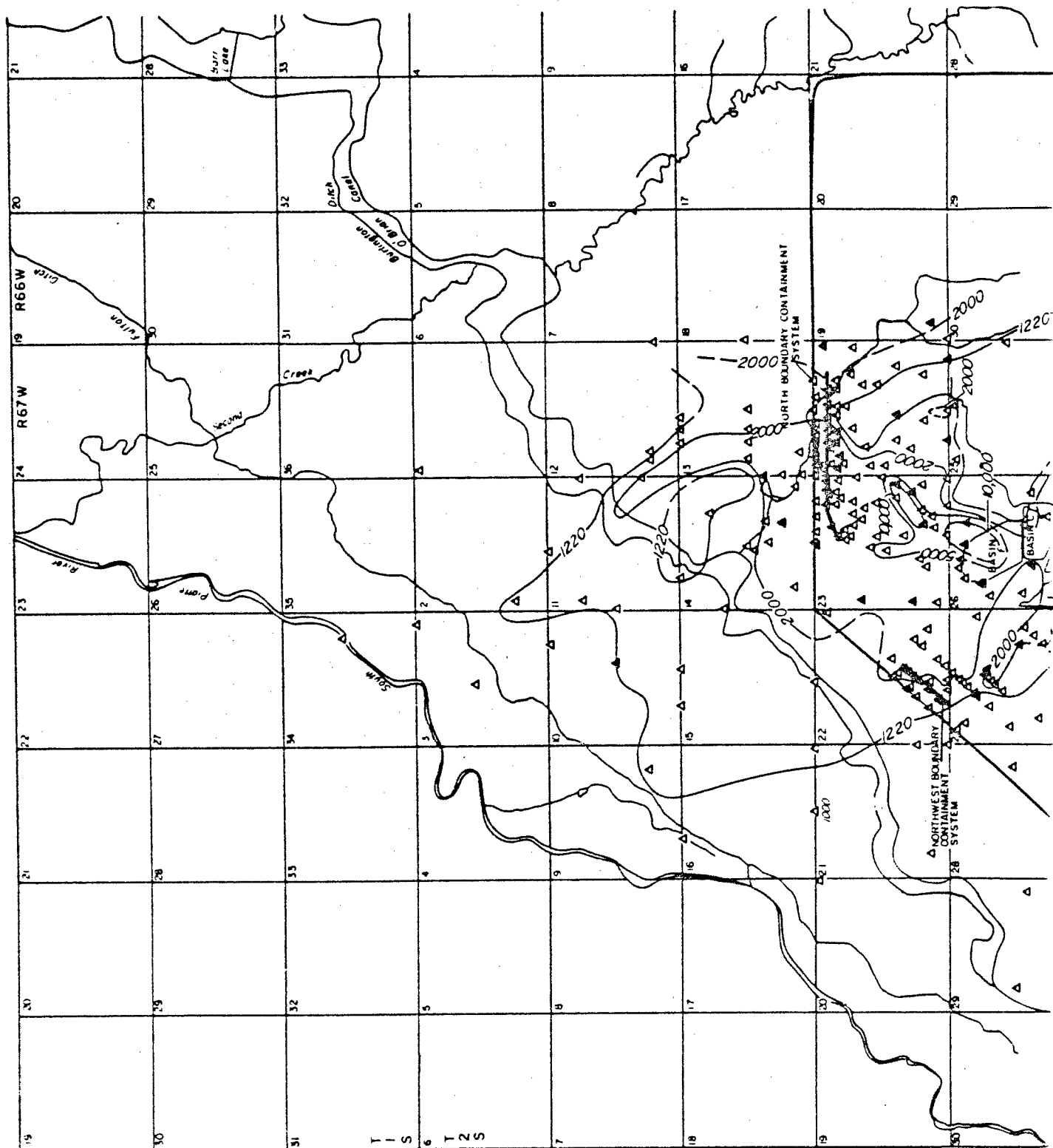
- △ Alluvial Well
- ▲ Unconfined Denver Formation Well
- Isoconcentration Line, Dashed Where Inferred
- △⁹ 37 Isolated Detection Or Detection Less Than Highest CRL, in ug/l
- Contour Interval Varies

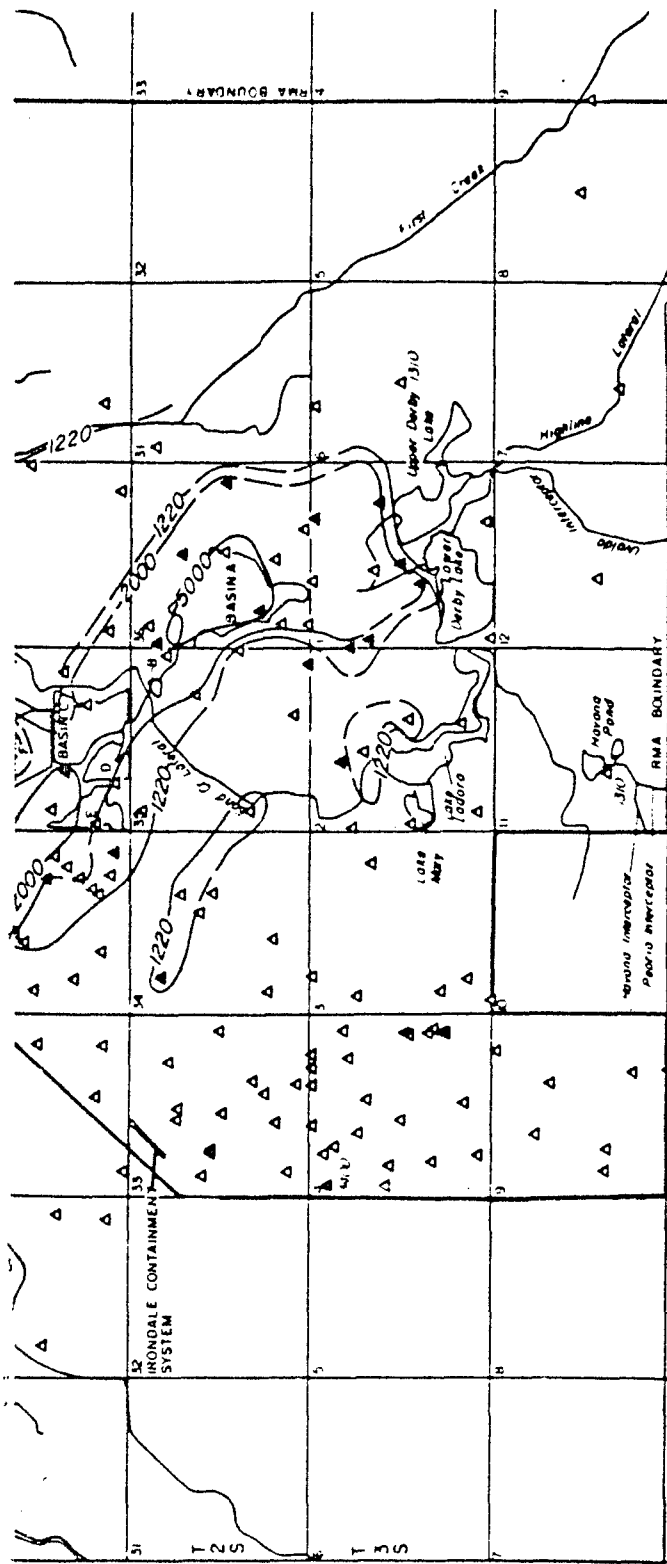
Figure 4.2-21

ARSENIC PLUMES UNCONFINED GROUNDWATER FLOW SYSTEM
3RD QUARTER FY 1987

SOURCE: Hunter/ESE, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland





EXPLANATION

- △ Alluvial Well
- ▲ Unconfined Denver Formation Well
- Isolated Detection Or Detection Less Than Highest CRL, in ug/l
- △ 110 Contour Interval Varies

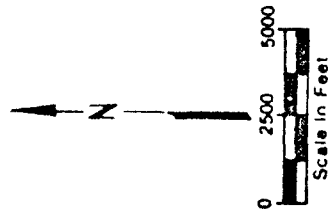


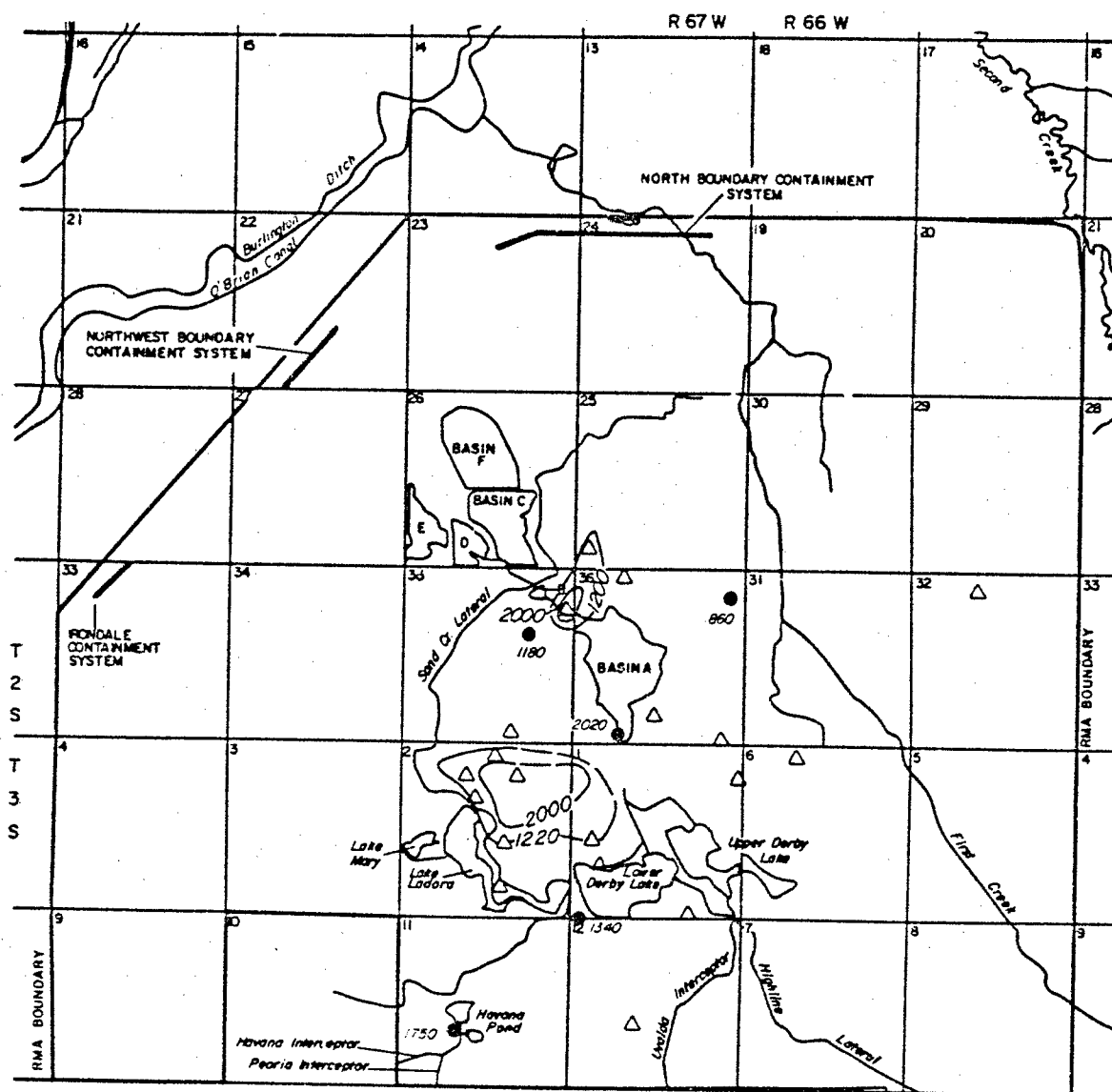
Figure 4.2-22

FLUORIDE PLUMES UNCONFINED GROUNDWATER FLOW SYSTEM
3RD QUARTER FY 1987

SOURCE HLA, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal

Aberdeen Proving Ground, Maryland



EXPLANATION

- △ Confined Denver Fm Well
- Equiconcentration Line
Dashed Where Inferred
- Isolated Detection Or
Detection Less Than
Highest CRL, In ug/l
- Contour Interval Varies

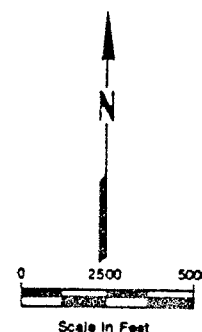
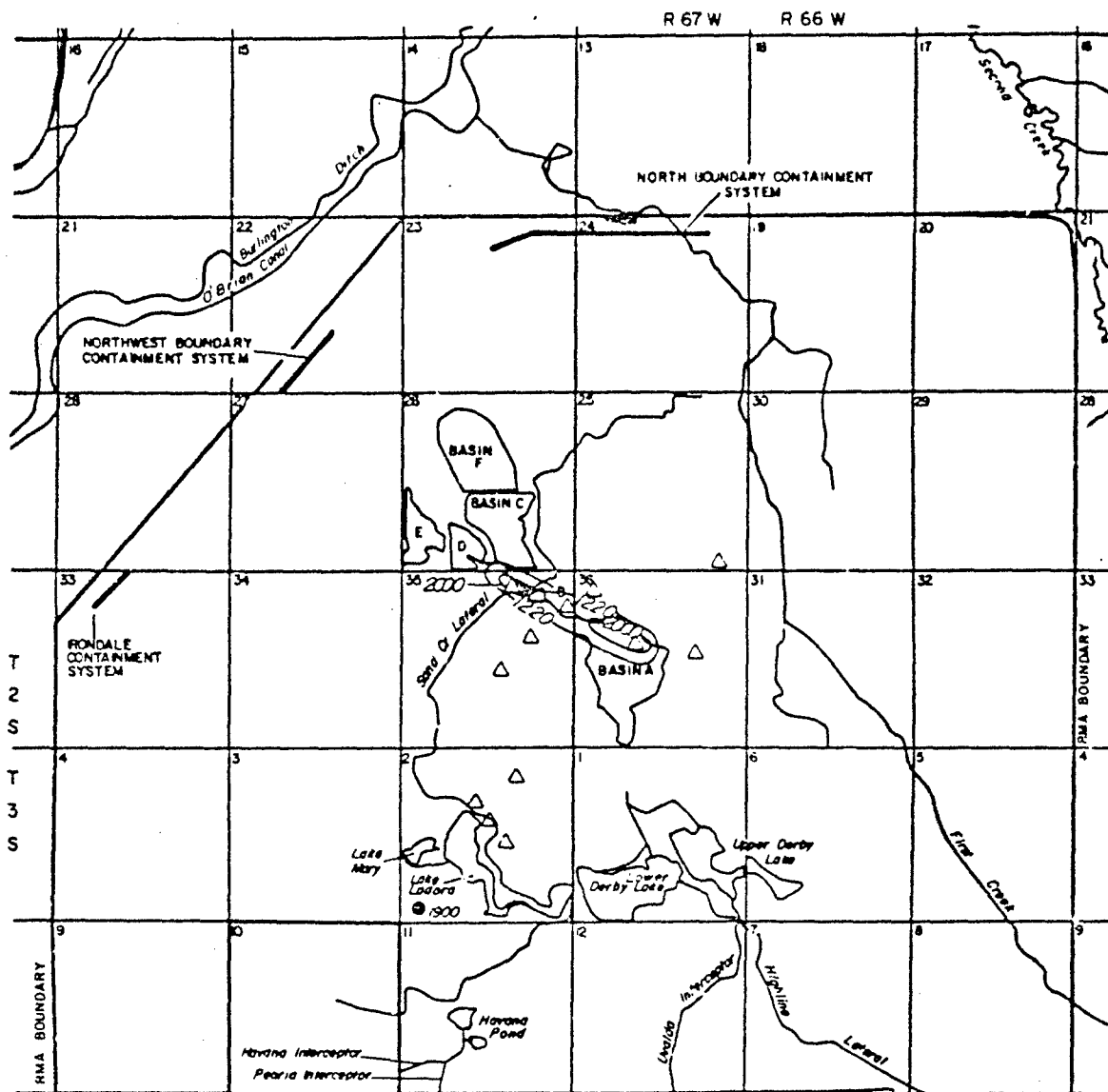


Figure 4.2-23

FLUORIDE PLUMES CONFINED DENVER FM
ZONE A, 3RD QUARTER FY 1987

SOURCE: HLA, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland



EXPLANATION

- △ Confined Denver Fm Well
- Equiconcentration Line
- 1900 Isolated Detection Or Detection Less Than Highest CRL, In ug/l
- Contour Interval Varies

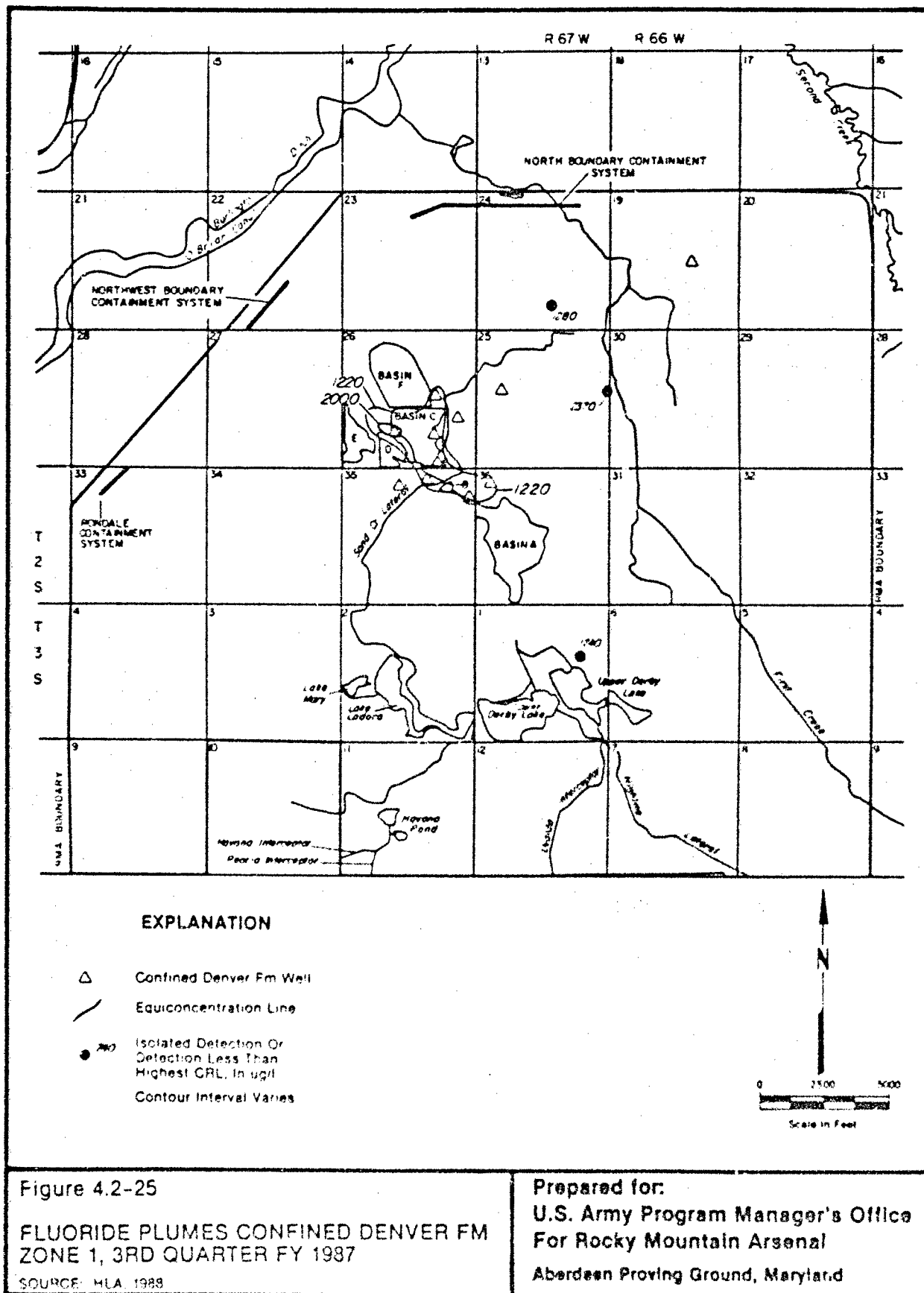


Figure 4.2-24

FLUORIDE PLUMES CONFINED DENVER FM
ZONE 1U, 3RD QUARTER FY 1987

SOURCE: HLA, 1988

Prepared for:
U S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland



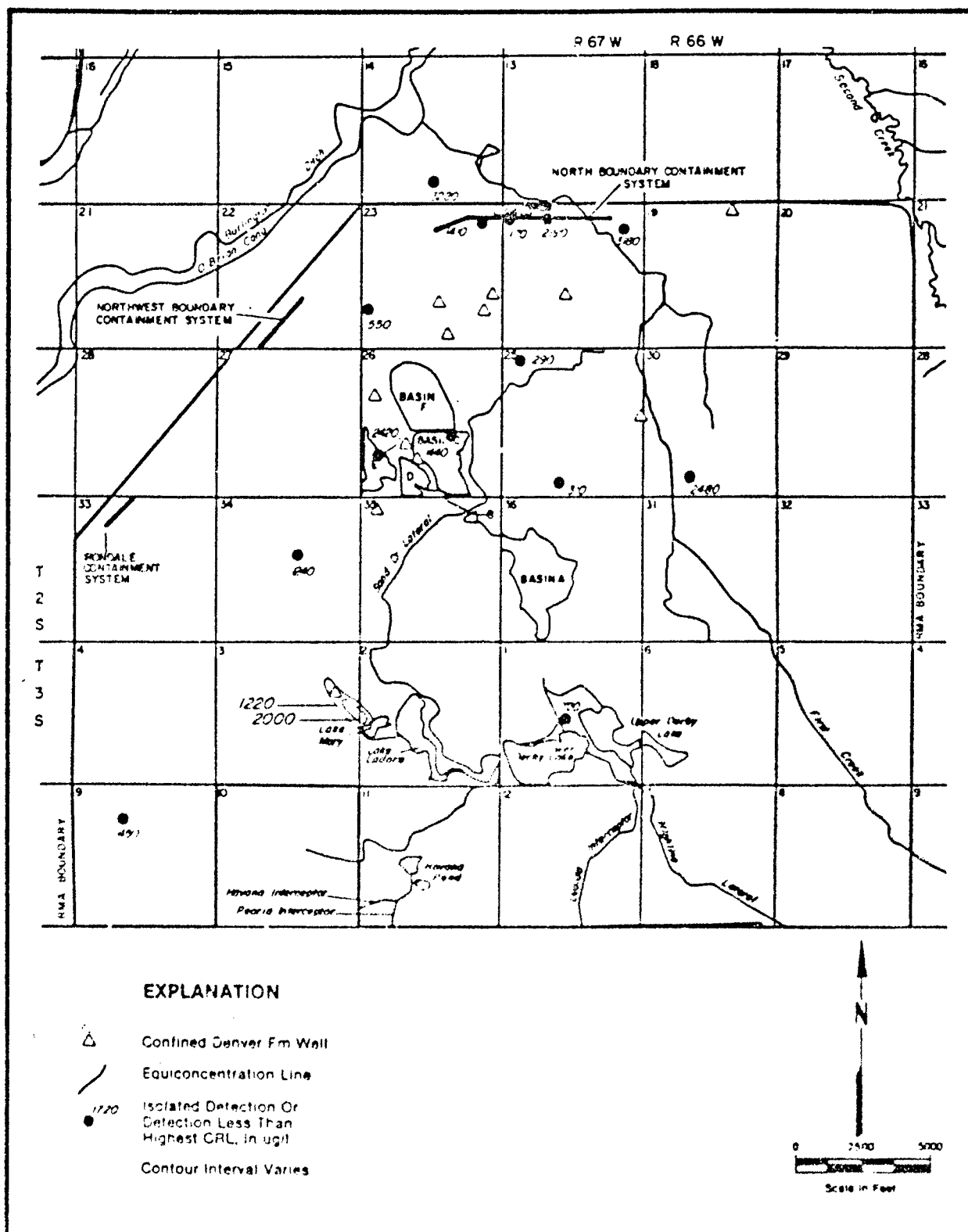


Figure 4.2-26

FLUORIDE PLUMES CONFINED DENVER FM
ZONE 2, 3RD QUARTER FY 1987

SOURCE: HLA, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland

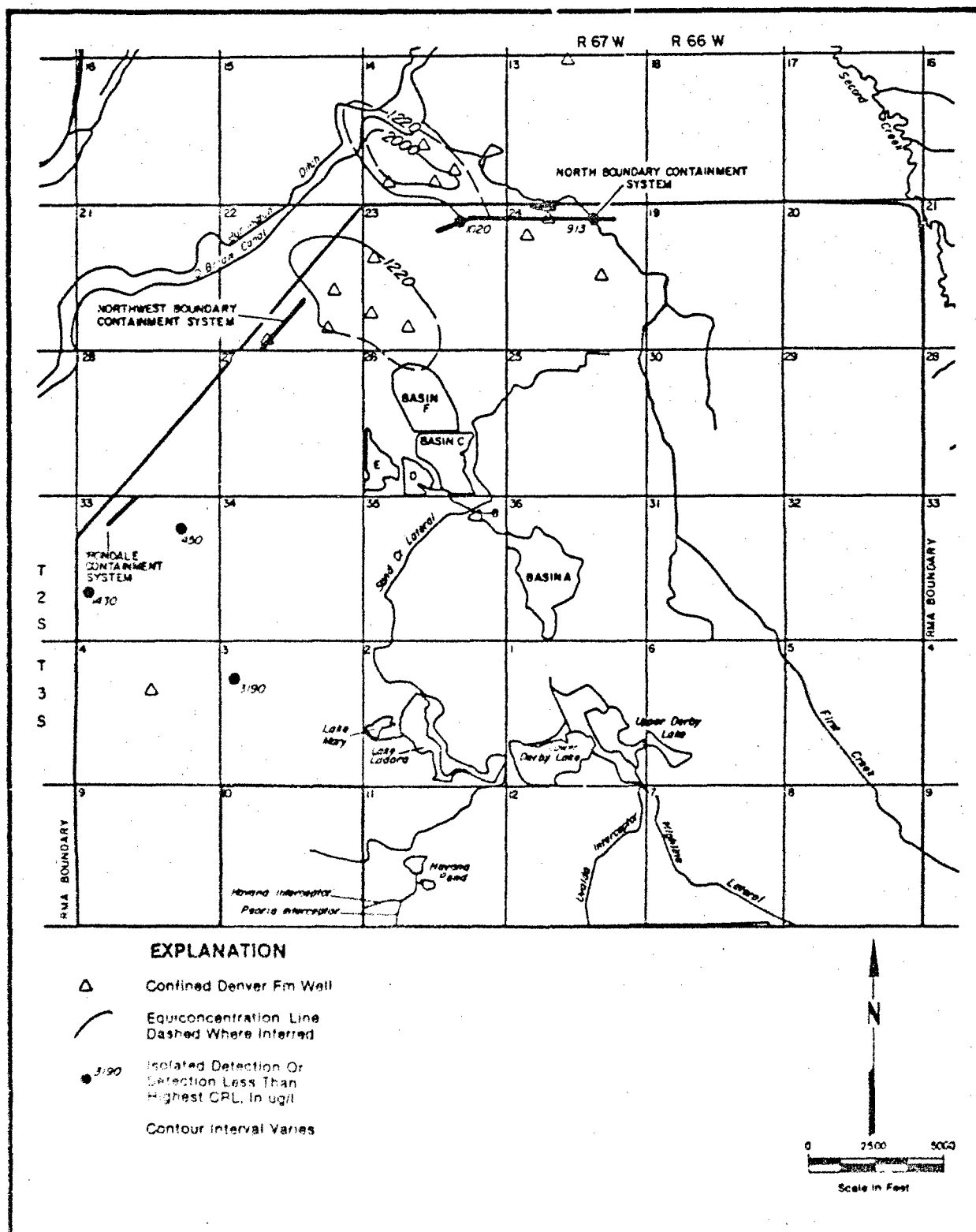


Figure 4.2-27

FLUORIDE PLUMES CONFINED DENVER FM
ZONE 4, 3RD QUARTER FY 1987

SOURCE: HLA, 1988

Prepared for:

U.S. Army Program Manager's Office
For Rocky Mountain Arsenal

Aberdeen Proving Ground, Maryland

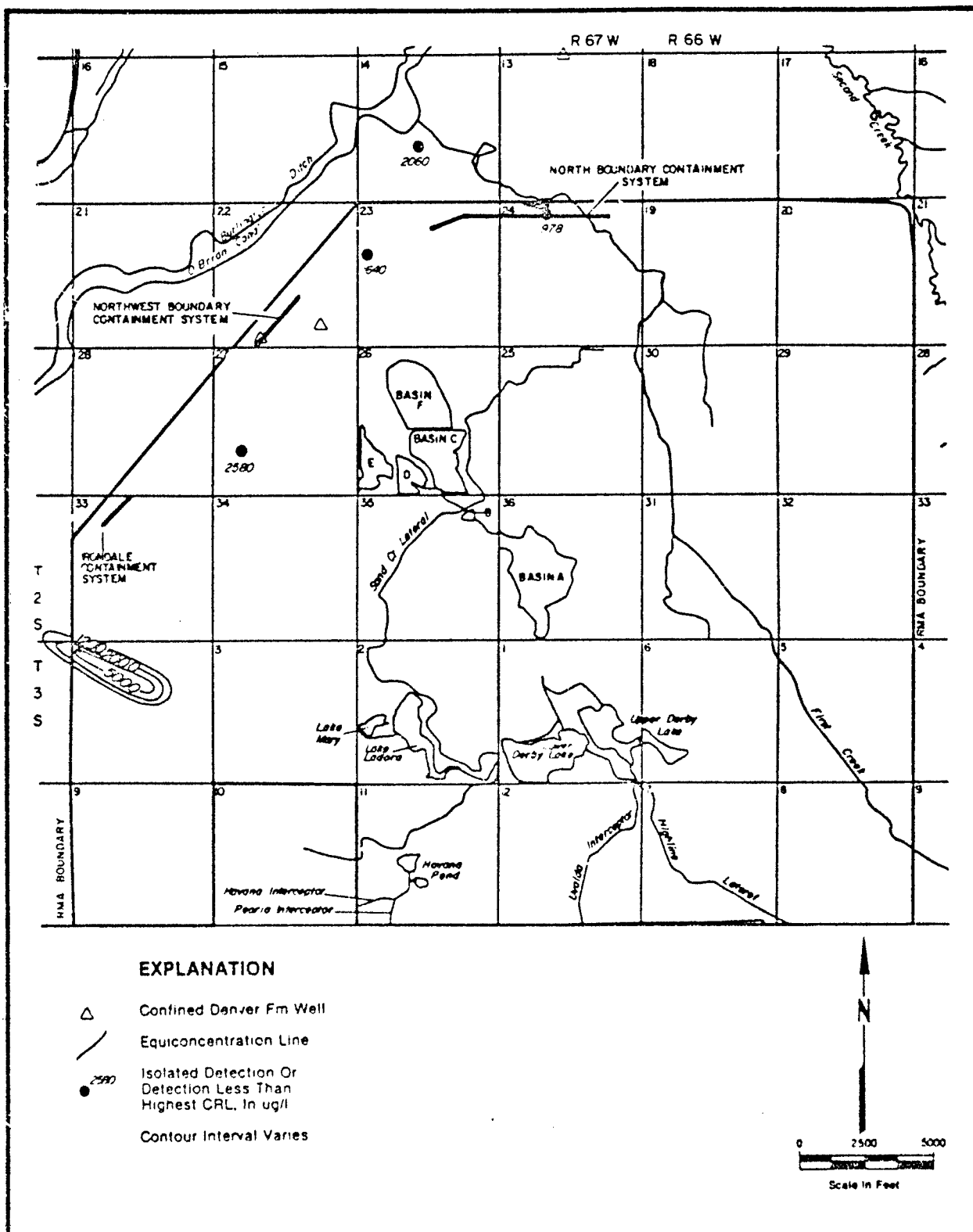
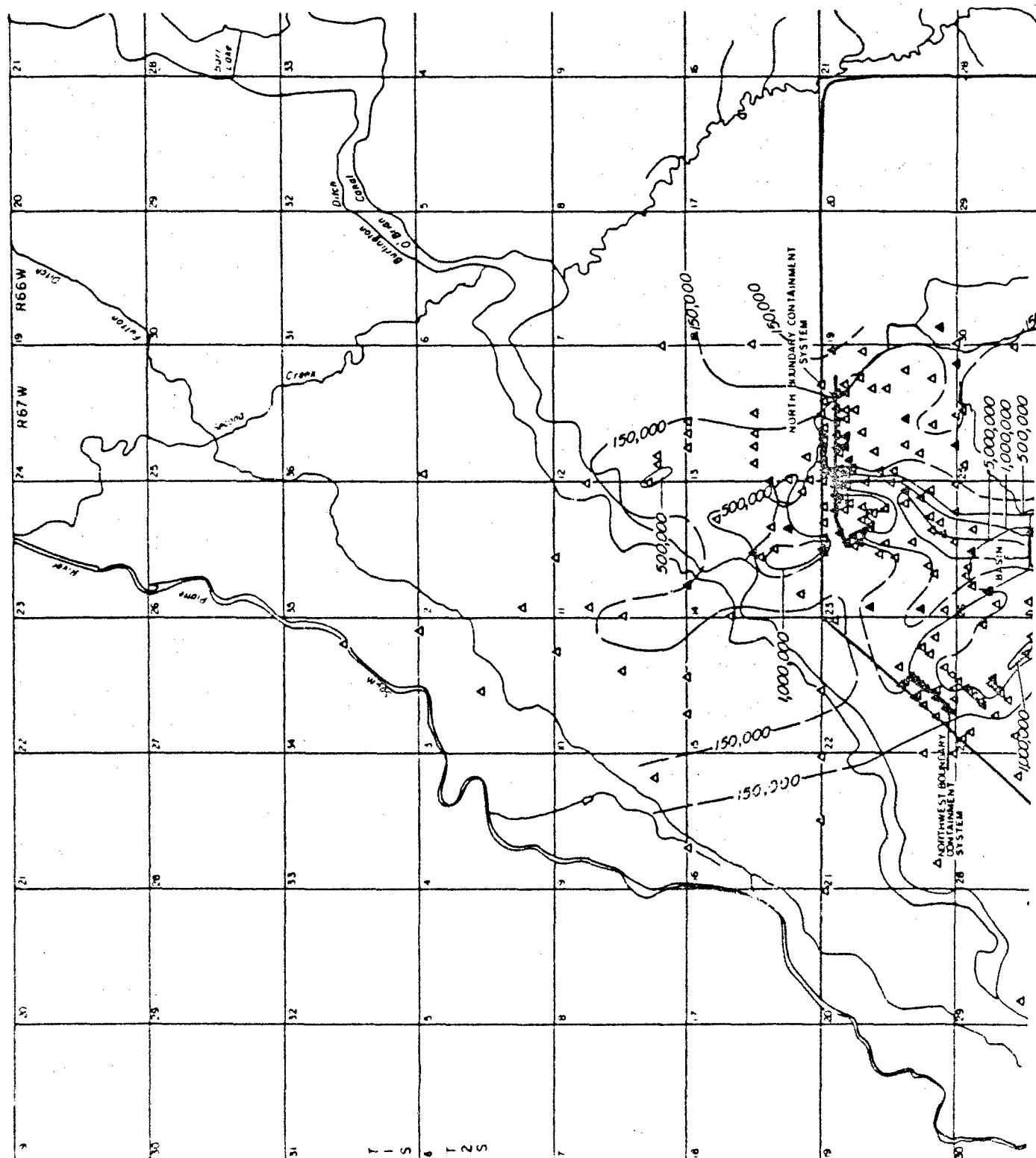


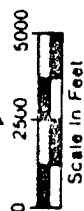
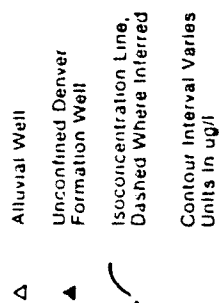
Figure 4.2-28

FLUORIDE PLUMES CONFINED DENVER FM
ZONE 5, 3RD QUARTER FY 1987

SOURCE: HLA, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland





CHLORIDE PLUMES UNCONFINED GROUNDWATER FLOW SYSTEM
3RD QUARTER FY 1987

**Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal**

SOURCE: Hunter/ESE, 1988

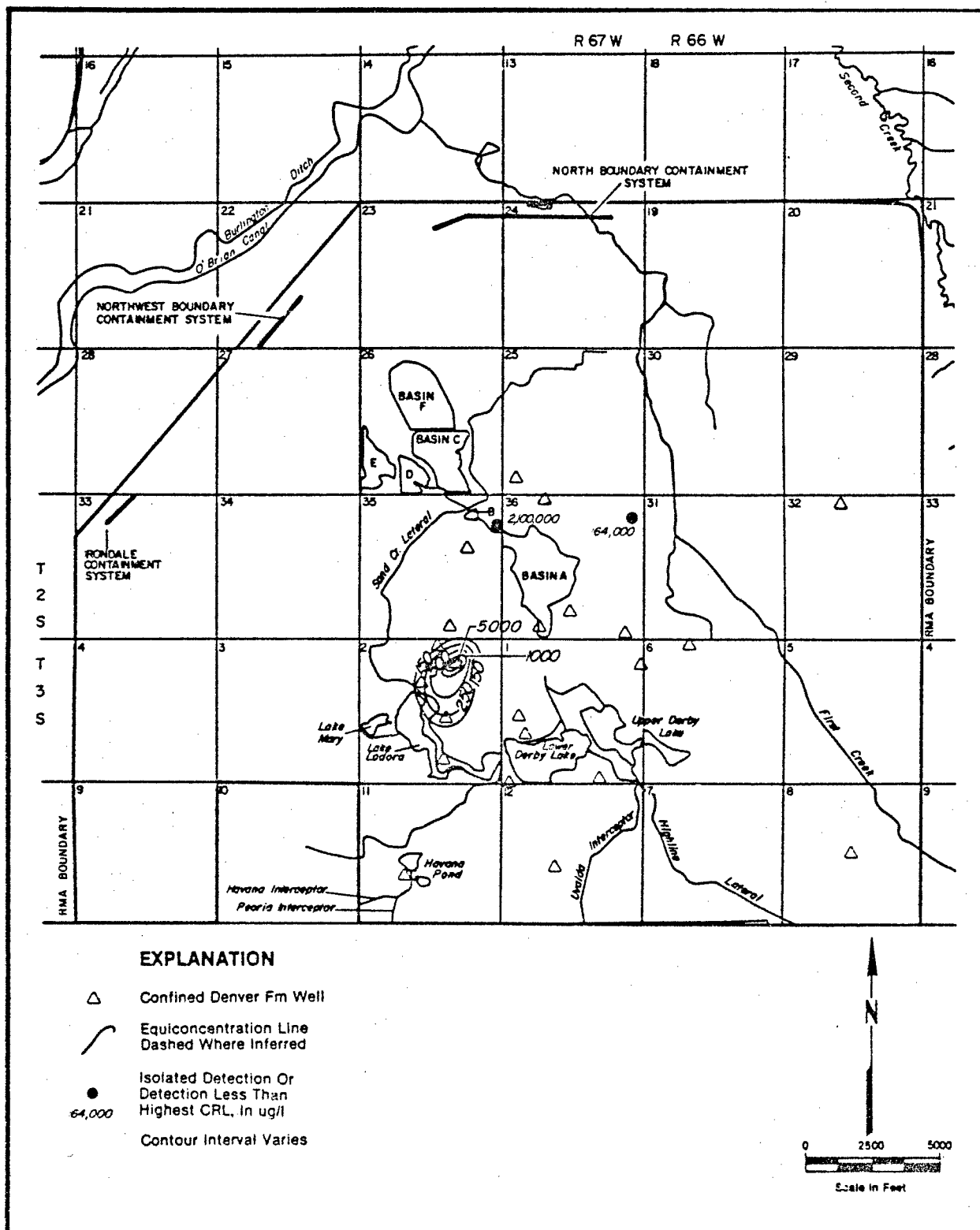
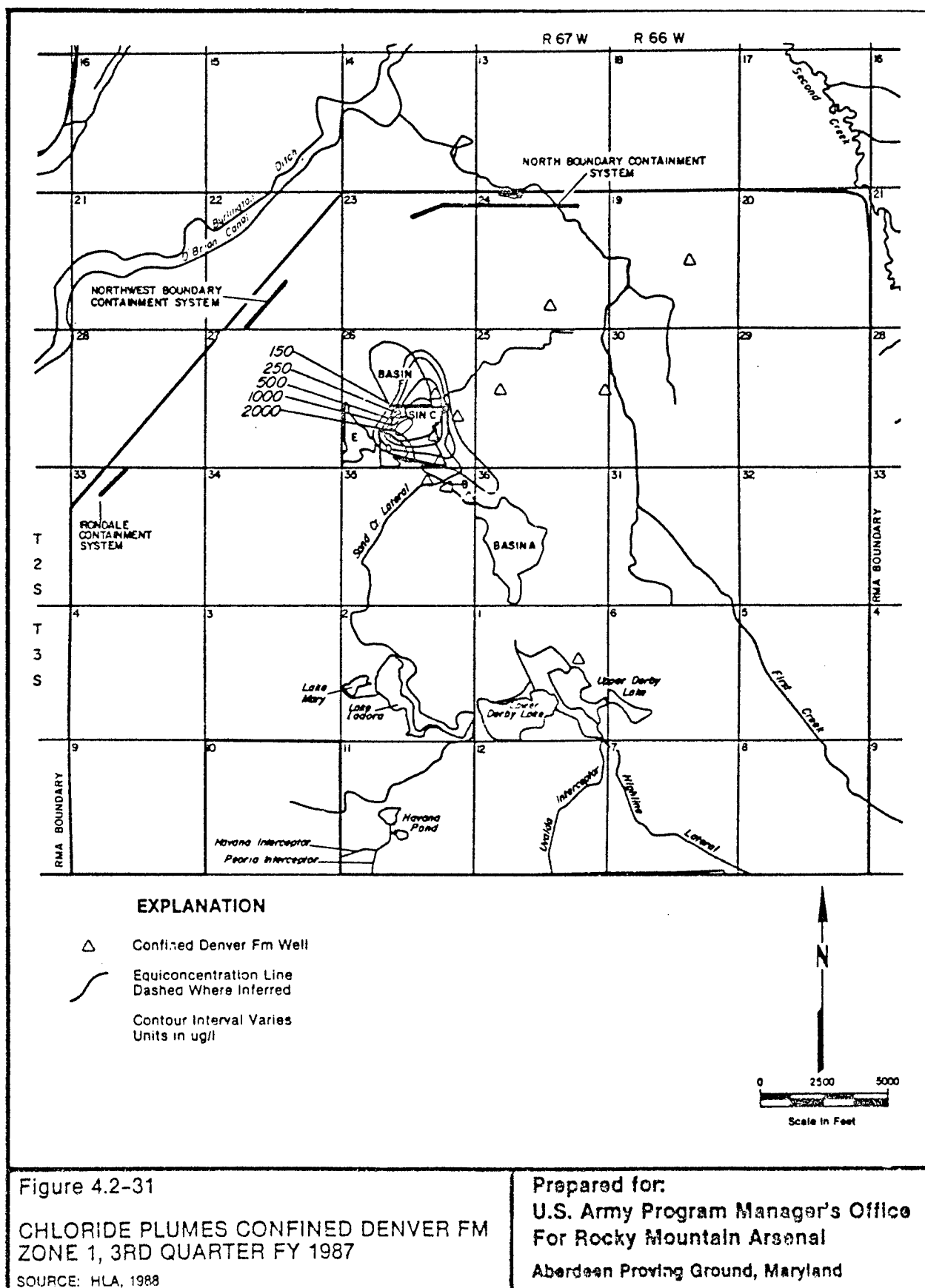


Figure 4.2-30

CHLORIDE PLUMES CONFINED DENVER FM
ZONE A, 3RD QUARTER FY 1987

SOURCE: HLA, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland



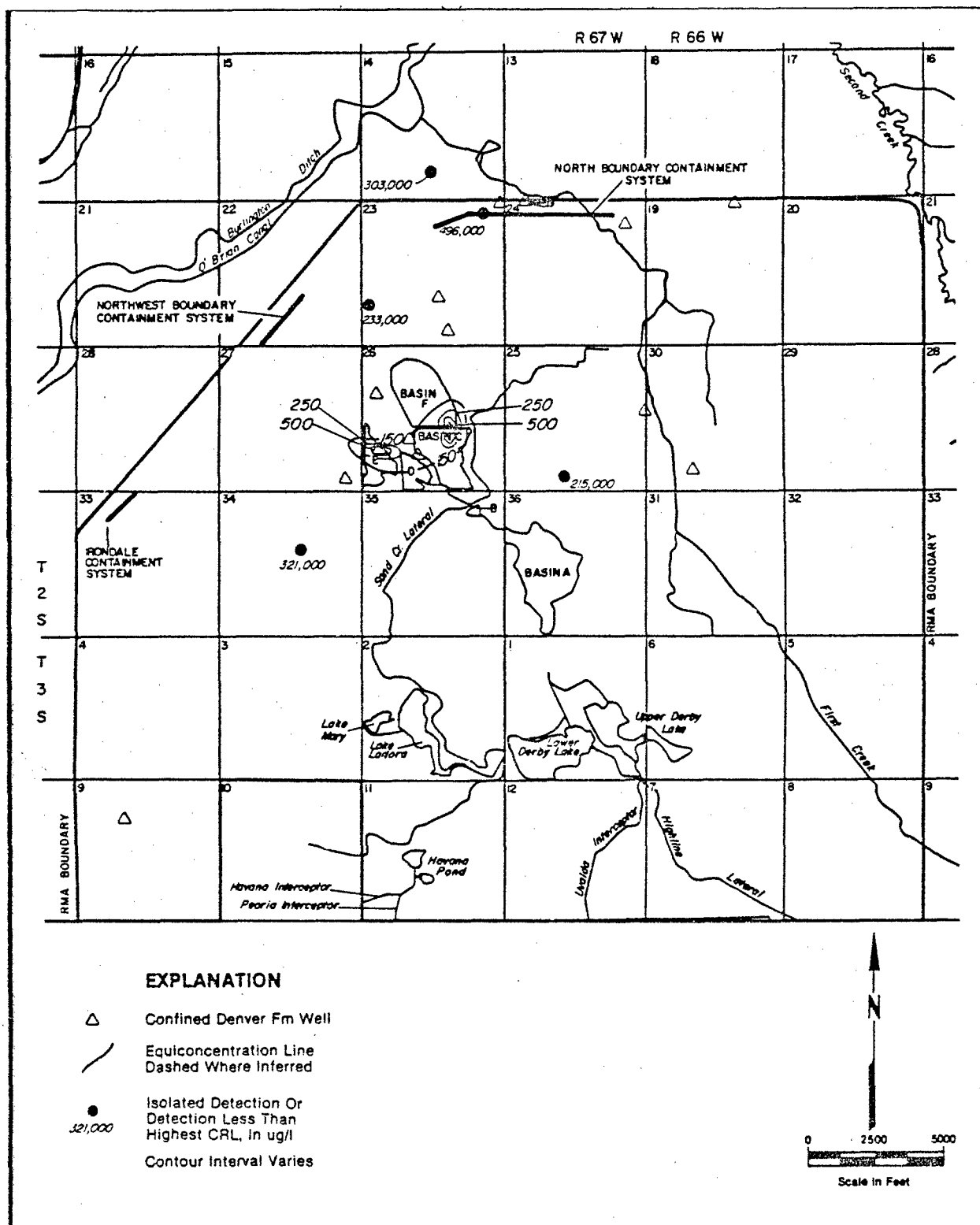
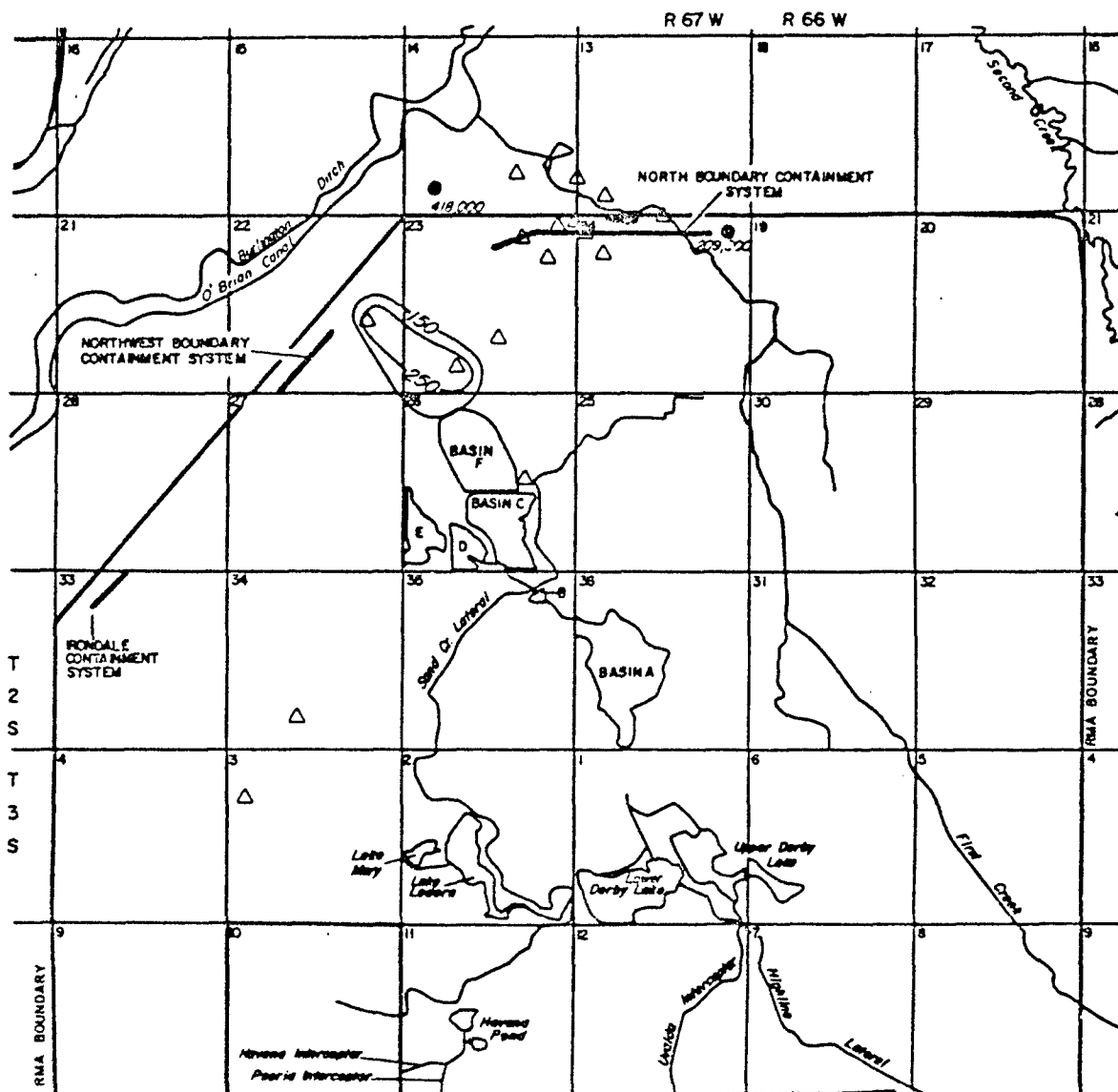


Figure 4.2-32

CHLORIDE PLUMES CONFINED DENVER FM
ZONE 2, 3RD QUARTER FY 1987

SOURCE: HLA, 1988

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal
Aberdeen Proving Ground, Maryland



EXPLANATION

- Confined Denver Fm Well
- Equiconcentration Line
Dashed Where Inferred
- Isolated Detection Or
Detection Less Than
Highest CRL, in ug/l
418,000
- Contour Interval Varies

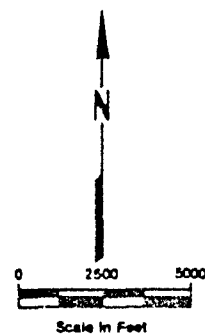


Figure 4.2-33

CHLORIDE PLUMES CONFINED DENVER FM
ZONE 3, 3RD QUARTER FY 1987

SOURCE: HLA, 1988

Prepared for:

U.S. Army Program Manager's Office
For Rocky Mountain Arsenal

Aberdeen Proving Ground, Maryland

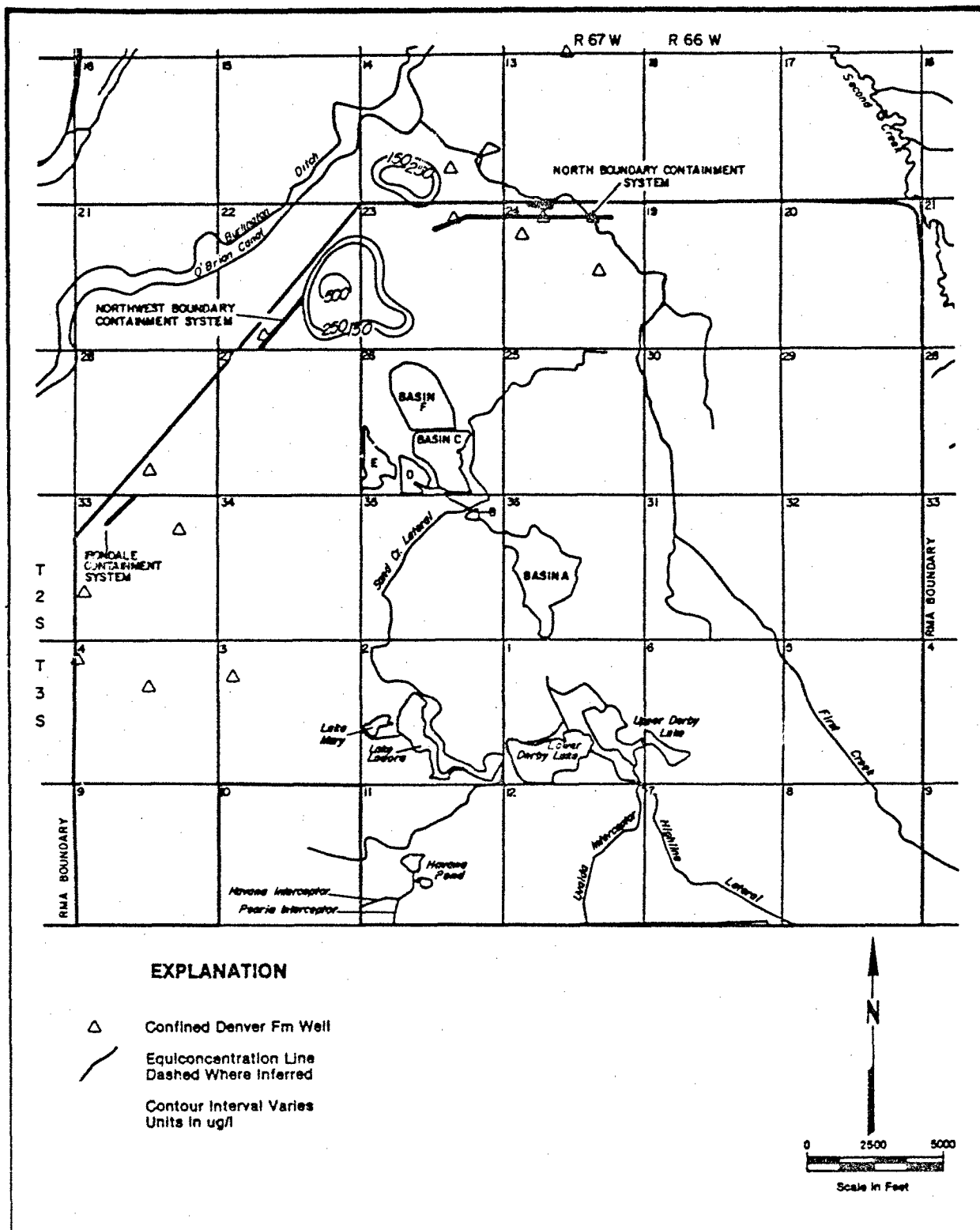


Figure 4.2-34

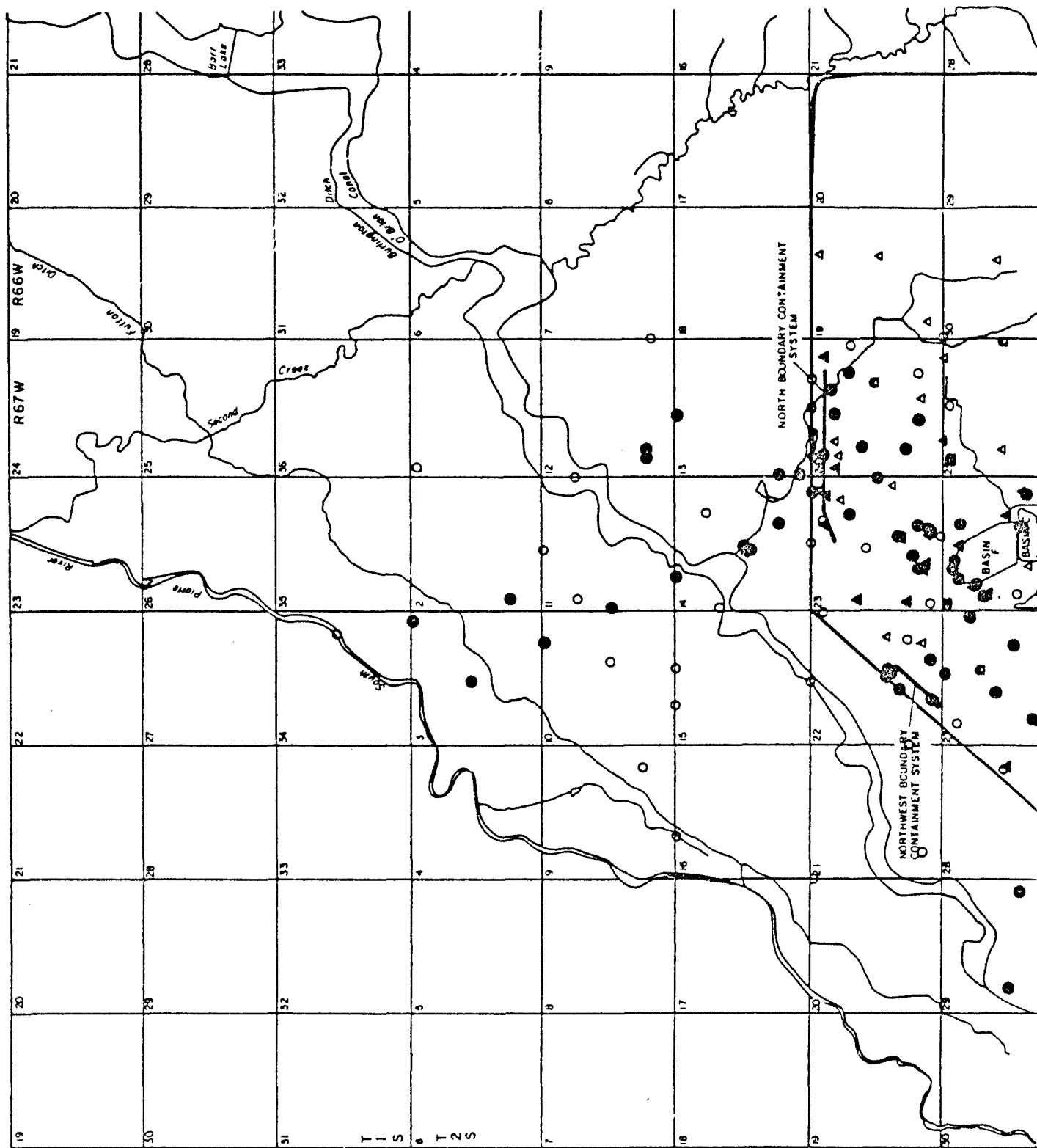
CHLORIDE PLUMES CONFINED DENVER FM.
ZONE 4, 3RD QUARTER FY 1987

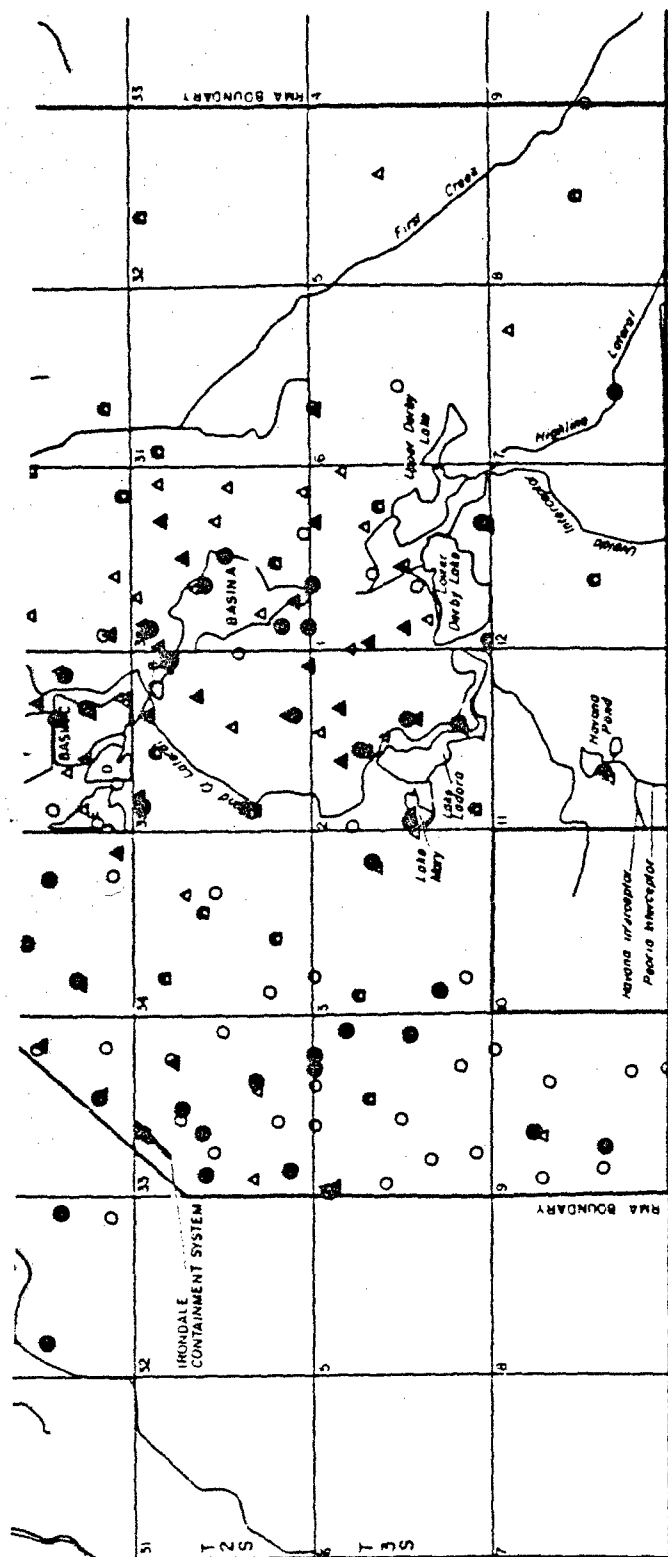
SOURCE: HLA, 1988

Prepared for:

U.S. Army Program Manager's Office
For Rocky Mountain Arsenal

Aberdeen Proving Ground, Maryland





EXPLANATION

- Alluvial Well
- △ Task 4/44 Denver Well
- Task 4/44 Alluvial GC/MS Analysis
- ▲ Task 4/44 Denver GC/MS Analysis

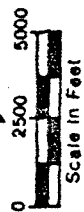
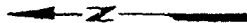


Figure 4.3-1

TASK 4/44 SAMPLING NETWORK AND WELLS SELECTED FOR GC/MS ANALYSIS

Prepared for:
U.S. Army Program Manager's Office
For Rocky Mountain Arsenal

SOURCE: Hunter/ESE, 1988

Aberdeen Proving Ground, Maryland